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Miners' Circular 55
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FIRES, GASES, AND VENTILATION IN METAL AND NONMETALLIC MINES

Metal- and Nonmetallic-Mine Accident-Prevention Course—Section 5

(Revised January 1955)

U. S. DEPARTMENT OF THE INTERIOR
March 3, 1849

U.S. Bureau of Mines

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UNITED STATES GOVERNMENT PRINTING OFFICE
WASHINGTON : 1957

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UNITED STATES DEPARTMENT OF THE INTERIOR
Fred A. Seaton, Secretary

BUREAU OF MINES
Marling J. Ankeny, Director

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FIRES, GASES, AND VENTILATION IN METAL AND NONMETALLIC MINES[1]

Metal- and Nonmetallic-Mine Accident-Prevention Course—Section 5

Revised by

Frank E. Cash[2]

PURPOSE AND SCOPE

The first metal-mine accident-prevention course was prepared and published in 1942–45 as a series of seven miners' circular (Nos. 51–57). The scope of the course has been broadened, revised, and brought up to date and is being published as a similar series of seven miners' circular (Nos. 51–57, revised) on accident prevention in metal and nonmetallic mines. These circulars are:

Accident Statistics (Miners' Circular 51), dealing with general statistics on accidents and injuries at metal and nonmetallic mines, including causes, costs, and the uses of investigations and reports of all accidents.

Falls of Rock or Ore (Miners' Circular 52), discussing the selection of mining methods to minimize the hazards of falling and sliding ground, the use of various types of support, and the protection of employees from falls of ground.

Hoisting and Haulage (Miners' Circular 53), presenting the hazards of hoisting and haulage at metal and nonmetallic mines and means of preventing accidents.

Explosives (Miners' Circular 54), giving information on accidents and injuries due to storing, handling, and using explosives in metal and nonmetallic mines and precautions for preventing them.

Fires, Gases, and Ventilation (Miners' Circular 55), explaining the causes of fires in metal and nonmetallic mines and the measures used to prevent, control, and extinguish them; describing gases found in mines and methods of detection and personal protection; and discussing the necessity for and standards of proper ventilation.

Electrical and Mechancial Hazards (Miners' Circular 56), covering accidents and injuries from electricity and machinery and their prevention and injuries from falls of persons.

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[1] Work on manuscript completed January 1955.

[2] Mining engineer, Bureau of Mines.

Health and Miscellaneous Hazards (Miners' Circular 57), including data on dust hazards, means of protection, and sampling devices; protective clothing and equipment; and illumination, supervision, discipline, and safety training for employees in metal and nonmetallic mines.

These seven circulars do not contain all the material that may be desired on every phase of accident prevention at metal and nonmetallic mines, but they will serve as bases for discussion. To them may be added supplementary material of particular interest in the field where the course is utilized. This accident-prevention course, offered to the mining industry by the Bureau of Mines, was compiled from studies by the Bureau and experience and knowledge gained by its engineers, to which is added information on safe-mining practices made available by mining companies and their officials.

This is the fifth section of the revised series of circulars that covers various phases of accident prevention in metal and nonmetallic mines; it explains the causes of mine fires and the measures used to prevent, control, and extinguish them; describes the occurrence of gases in mines and methods for their detection; and discusses the necessity for and standards of ventilation. The related subjects of mine fires, gases, and ventilation are important to the operation of most mines, large or small, and all mine officials should understand the simple, basic facts of these subjects.

ACKNOWLEDGMENTS

Much of the original text is retained in the revised course on Accident Prevention in Metal and Nonmetallic Mines.

The circulars were revised under the general supervision of James Westfield, Assistant Director, Health and Safety, William J. Fene, chief, Division of Safety, and Simon H. Ash, former chief, Safety Branch, Bureau of Mines.

This section, Fires, Gases, and Ventilation, was revised by Frank E. Cash; supplmental material was supplied by the following Bureau engineers:

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The manuscript was reviewed by Louis H. McGuire, Lester L. Naus, Douglas H. Platt, and Roy G. Stott.

The illustrations were obtained from mining and manufacturing companies and Bureau of Mines publications.

MINE FIRES

Although mine fires are not a major cause of metal- and nonmetallic-mine accidents, there has been great loss of life in some metal- and nonmetallic-mine fires, and in many the property loss has been heavy. Any mine fire in active workings is likely to endanger life, as even a small fire may give off enough noxious gases to expose men in widely separated places to the dangers of suffocation. A small fire can quickly grow into a gravely serious one, and its control and extinguishment may involve large expenditures in labor, materials, and loss of production and even loss of ore where the fire area cannot be reclaimed. The results of mine fires are often more serious than appear at a casual glance. The direct costs of fighting the fire and reclaiming the mine are high for a fire of only moderate extent. Once a fire gets beyond control, the expense mounts rapidly. Such a fire in a timbered drift may cost $10,000 to $50,000; a fire in a timbered shaft may cost a million dollars or more, when all the losses are included, and several fires involving large parts of ore bodies have cost several million dollars each before the fire was finally halted and mining resumed in that region.[3]

The probable property loss from fire may be so small at many mines that protective measures appear of little importance, but because of the ever-present possibility of loss of life from fire in or about a mine, precautions corresponding to the degree of risk should be taken. Although the total number of men killed by mine fires is less than that ascribed to any one of several other causes of mine fatalities, the possibility of killing a large group of men at one time makes it very important to prevent fires and provide for the protection of men against their effects at nearly all mines.

With the increasing use of belt conveyors and electrically operated mobile loaders and shuttle cars with trailing cables, ignitions or incipient fires in metal and nonmetallic mines may increase unless such equipment is properly installed, guarded, maintained, and operated.

MINE-FIRE STATISTICS

According to Bureau of Mines records, 93 metal- and nonmetallic-mine fires caused 13 fatal and 98 nonfatal injuries (total, 111), which is only 0.06 percent of the total injuries that occurred at underground metal and nonmetallic mines during 1932–54 (table 1). In the preceding 20-year period 321 persons died in mine fires, virtually all from suffocation.

The Bureau of Mines attempts to obtain information concerning fires in mines of the United States, but the less destructive fires are not always brought to its attention. Hundreds of incipient fires that are quickly extinguished occur every year and are not reported to the Bureau of Mines or State inspection departments.

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[3] Harrington, D., Pickard, B. O., and Wolflin, H. M., Metal-Mine Fires: Bureau of Mines Tech. Paper 314, 1923, p. 2.

TABLE 1.—*Injuries from underground fires at metal and nonmetallic mines, 1932–54*[1]

[Prepared by the Accident-Analysis Branch, Health and Safety Division]

Year	Man-hours (millions)	Fatal				Nonfatal			
		All causes (total)	Mine fires	Percent of total	Frequency rate[1]	All causes (total)	Mine fires	Percent of total	Frequency rate[1]
1932	83.5	105	------	------	------	4,767	1	(2)	0.01
1933	81.8	90	------	------	------	5,555	------	------	------
1934	101.1	101	------	------	------	7,440	------	------	------
1935	141.1	154	------	------	------	9,677	12	0.1	.09
1936	177.7	185	------	------	------	13,916	8	.1	.05
1937	210.3	207	------	------	------	17,191	1	(2)	(3)
1938	166.8	145	2	1.4	0.012	12,052	9	.1	.05
1939	181.6	157	------	------	------	13,019	1	(2)	.01
1940	201.6	200	------	------	------	13,982	1	(2)	(3)
1941	207.0	201	2	1.0	.010	14,601	7	(2)	.03
10-year total	1,552.4	1,545	4	------	------	112,200	40	------	------
10-year average	155.2	155	(4)	.3	(3)	11,220	4	(2)	.03
1942	198.8	206	8	3.9	.040	12,682	5	(2)	.03
1943	183.8	189	------	------	------	11,758	13	.1	.07
1944	146.9	127	------	------	------	9,100	4	(2)	.03
1945	126.5	101	------	------	------	7,213	2	(2)	.02
1946	121.7	101	------	------	------	7,817	6	.1	.05
1947	139.9	128	------	------	------	8,632	10	.1	.07
1948	142.3	99	1	1.0	(3)	7,849	7	.1	.05
1949	128.6	73	------	------	------	7,242	4	(2)	.03
1950	139.9	101	------	------	------	6,995	3	(2)	.02
1951	134.7	94	------	------	------	7,212	4	(2)	.03
10-year total	1,463.1	1,219	9	------	------	86,500	58	------	------
10-year average	146.3	122	1	.1	(3)	8,650	6	(2)	.04
1952	133.9	115	------	------	------	6,959	2	(3)	.01
1953	128.9	98	8	8.2	.062	6,683	1	(3)	.01
1954	112.9	74	------	------	------	5,292	2	(3)	.02

[1] Per million man-hours.
[2] Less than 0.1 percent.
[3] Less than 0.01 injury.
[4] Average less than 1 injury.

The Bureau of Mines considers an accident causing five or more fatalities as a major disaster. In this category there were 93 such accidents resulting in 1,227 fatalities from 1869 through 1944 at metal and nonmetallic mines and quarries.[4] Of these 93 disasters, 30, resulting in 551 fatalities, were due to mine fires, gas and dust explosions and exposure to mine gases.

In the past 10 years (January 1, 1945, to July 31, 1954) there have been 6 disasters at metal and nonmetallic mines and quarries, causing 33 fatalities, as follows:

1. **February 20, 1945**: 5 men were burned to death at a bunkhouse on the surface at a lead-zinc mine.
2. **July 16, 1950**: 5 men died during an underground fire in a zinc mine.
3. **July 24, 1952**: 5 men were killed by the collapse of a trestle at a rock quarry.
4. **October 3, 1952**: 5 men were killed by a gas explosion in a prospect shaft through a carbonaceous shale that was known to give off methane gas.
5. **November 5, 1953**: 8 men were killed by a gilsonite dust explosion.
6. **March 31, 1954**: 5 men were killed at an opencut copper mine by a premature dynamite explosion.

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[4] Hyvarinen, John, Johnson, L. H., and Kennedy, D. O., Major Disasters at Metal and Nonmetal Mines and Quarries in the United States: Bureau of Mines Inf. Circ. 7493, 1949, 26 pp.

These disasters bring the total to 99, with 1,260 fatalities. They are listed by causes and operations in table 2.

The disasters and fatalities by principal products are, respectively: Copper, 25 and 371; gold, silver, and miscellaneous metals, 26 and 344; iron, 15 and 235; lead and zinc, 11 and 107; and nonmetallic minerals, including quarries, 22 and 203.

The Mining Act (1928) of Ontario, Canada, requires that every fire, large or small, occurring underground or on the surface, that endangers operations underground be reported to the Department of Mines.

There were 115 fires in the 21-year period 1928–48 [5] at underground metal and nonmetallic mines in Ontario. These fires caused 44 fatal injuries, all during 1928–33.

Table 3 summarizes the causes and locations of the 115 fires.

TABLE 2.—*Disasters at metal and nonmetallic mines and quarries in the United States, 1869–1954, by causes and locations*

Cause	Underground mines				Opencut mines		Quarries		Total	
	Surface		Underground							
	Number	Fatalities	Number	Fatalities	Number	Fatalities	Number	Fatalities	Number	Fatalities
Fires	5	55	18	405	------	------	------	------	23	460
Explosions (gas and dust)	------	------	5	41	------	------	------	------	5	41
Natural gases (low-oxygen)	------	------	1	6	------	------	------	------	1	6
Explosives	2	26	11	131	4	38	13	141	30	336
Falls and slides of rock or ore	2	25	9	66	2	21	3	17	16	129
Rock bursts or air blasts	------	------	2	12	------	------	------	------	2	12
Inrush of water and mud	------	------	7	168	------	------	------	------	7	168
Hoisting	2	24	8	56	------	------	------	------	10	80
Haulage	1	5	2	10	------	------	------	------	3	15
Machinery	1	6	------	------	------	------	1	7	2	13
Total	13	141	63	895	6	59	17	165	99	1,260

TABLE 3.—*Summary of 115 fires in underground metal and nonmetallic mines in Ontario, 1928–48*

Causes of fires	Hoisting circuits and facilities	Haulage facilities		Elsewhere	Total	Percent
		Battery	Trolley			
Electricity	12	20	6	16	54	47
Welding, cutting, riveting	10	----------	----------	8	18	16
Smoking (presumed)	5	----------	----------	4	9	8
Spontaneous combustion	1	----------	----------	4	5	4
Miscellaneous	7	----------	1	11	19	16
Unknown (not electrical)	8	----------	----------	2	10	9
Total	43	20	7	45	115	----------
Percent	37	18	6	39	100	100

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[5] Gibson, Clifford S., Fire Prevention at Ontario Mines: Proc. Lake Superior Mines Safety Council, 1949, pp. 110–123.

Not all mine fires occur at underground mines, nor do all mine fires result in injuries. A continued study[6] of mine fires in the Lake Superior iron-ore district, covering the period 1931–52, reveals interesting and valuable information.

During this 22-year period 188 underground fires were reported and analyzed. The causes of the fires are given as follows:

Cause	Total	Percent of total	Cause	Total	Percent of total
Electricity	117	62.2	Conveyor belt	1	0.5
Sulfur oxidation in slates	27	14.4	Drive belt on pump	1	.5
Welding, cutting, and blowtorches	22	11.7	Thawing air line with waste	1	.5
Smoking	6	3.2	Throwing burning paper into raise	1	.5
Open lights	4	2.1	Undetermined	2	1.2
Blasting	4	2.1			
Old timber in stopes	2	1.1	Total	188	100.0

The locations of these 188 fires are given as follows:

Location	Total	Percent of total	Location	Total	Percent of total
Sublevels	68	37.2	Pump rooms	6	3.2
Main levels	51	27.1	Raises and chutes	8	4.3
Stopes	12	6.4	Transformer room	1	.5
Shafts	19	10.1	Other	3	1.6
Shaft stations	13	6.9			
Shaft headframes	7	3.7	Total	188	100.0

The methods of extinguishing 137 of these are given as follows:

Methods	Number	Percent or total	Method	Number	Percent of total
Fire extinguishers	51	37.2	Fire spent itself	14	10.2
Water (pump, drill, and air line)	36	26.3	Fill material	6	4.4
Water and extinguishers	5	3.6			
Seals and bulkheads	25	18.3		137	100.0

Self-contained oxygen breathing apparatus were used in combatting 23 of these fires, and gas masks were used in many more.

NOTABLE MINE FIRES

The following notable examples of mine fires causing heavy loss of life and damage to property are part of the past experience on which fire-prevention practices are based. An impression of the destructiveness of a metal-mine fire may be gained from figures 1 and 2.

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[6] Fellman, C. M., Fires in Lake Superior Iron Mines: Proc. Lake Superior Mines Safety Council, 1941, pp. 96–112; Fires and Fire-Prevention Practices in Lake Superior District Iron Mines: Proc. Lake Superior Mines Safety Council, 1947, pp. 46–94.

Felegy, E. W., and Fellman, C. M., Fires and Fire-Prevention Practices in Lake Superior District Iron Mines: Proc. Lake Superior Mines Safety Council, 1952, pp. 33–100.

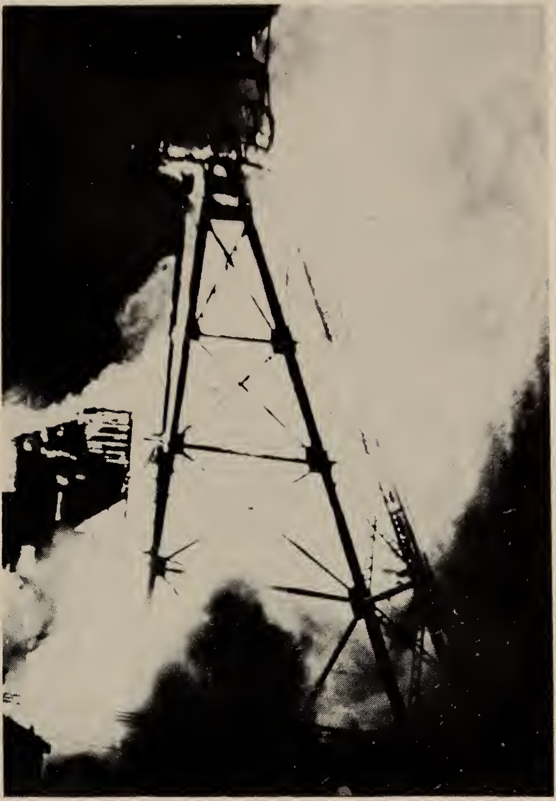

FIGURE 1.—Fire in Tonopah-Belmont Shaft, Tonopah, Nev.

Granite Mountain Shaft Fire, Butte, Mont.

A fire in one of the two main shafts of the North Butte mine, an underground copper property operated by the North Butte Mining Co., on the night of June 8, 1917, caused the death of 163 men—the greatest number killed in any American metal-mine disaster. When the fire occurred 410 men were underground. One main shaft, the Granite Mountain, was 3,740 feet deep and had 2 main hoisting compartments, as well as a third compartment, separated from the others by a solid timber partition, with a man cage, air lines, water lines, and electric power lines; it had a downcast air current. The other main shaft, the Speculator, about 800 feet from the Granite Mountain, was about 3,000 feet deep, was equipped with cages, and was connected by drifts or crosscuts to the Granite Mountain at the various levels. There were two subsidiary ventilation shafts, the Gem and the Rainbow, and various connections to other mines.[7]

The North Butte mine was one of the best ventilated mines in the Butte district. Two surface fans at the Gem and Rainbow shafts exhausted about

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[7] Harrington, D., Lessons From the Granite Mountain Shaft Fire, Butte: Bureau of Mines Bull. 188, 1922, 50 pp.

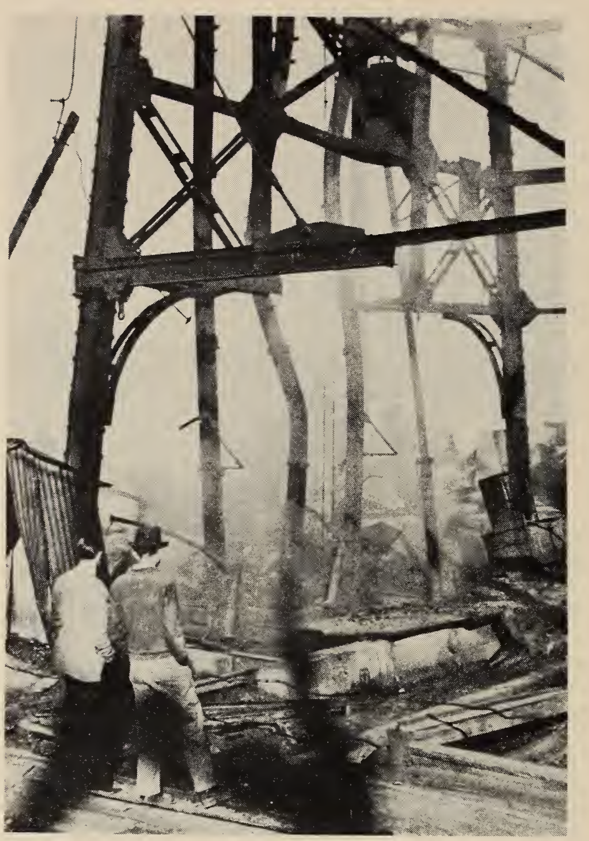

FIGURE 2.—Gases and Smoke From Tonopah-Belmont Mine Fire.

50,000 cubic feet of air per minute from the mine, and about 10,000 cubic feet of air per minute left the mine through the Speculator shaft, a natural upcast. A reversible fan at the collar of the Speculator shaft was not in operation when the fire started. These surface fans were augmented by a large number of auxiliary, electrically driven, underground fans with canvas pipe for carrying air to the faces. A large number of underground doors controlled the air currents.

Electricity was widely used underground for power, light, and the 15 trolley locomotives; it was available on virtually every level. Current at 2,300 volts potential was transmitted from the Granite Mountain shaft to a transformer station on the 2,600-foot level.

Just before the fire the North Butte Co. had started to pipe the shaft and place sprinklers in it to provide better fire protection. Small tanks were placed at intervals of a few hundred feet down the shaft to reduce and equalize the pressure. Plans had been made to move the main transformer station from the shaft at the 2,600-foot level back several hundred feet, partly as a fire-prevention measure. Preparatory to moving the transformer station at the 2,600-foot level, 6 men started to lower 1,200 feet of lead-armored cable into the shaft to be used in extending the main transmission line to the new station. The cable weighed 5 pounds per foot or 3 tons in all; it was lashed to a hoist rope by 4-foot lengths of hemp rope, placed every 10 feet for the first 500 feet and at 5-foot intervals thereafter. No clamps were used because of the possibility of crushing the cable. As the cable was about to be landed on the 2,600-foot level, it slipped from its lashings and fell, lodging in the shaft between the 2,400- and 2,800-foot levels and breaking water pipes; in its fall much of the lead armor was torn off, exposing and fraying the oil-impregnated cambric and jute insulation. Fully half of the cross section of the cable was oil-impregnated, highly flammable material. The cable was ruined, and at 11:30 p. m. on June 8 the assistant foreman, a shift boss, and 2 shaft men went just below the 2,400-foot level to try to attach the cable to the cage and pull it up. As the badly wrecked cable was being examined, the flame of a hand carbide lamp came in contact with the frayed, oil-soaked insulation, and a blaze started which forced these men to retire to the 2,400-foot station. With other men on the level, they tried to extinguish the fire, but in a few minutes the shaft timbers had become sufficiently ignited to change the normal downcast in one compartment of the Granite Mountain shaft to an upcast, and smoke started to spread through both the upper and lower levels of the mine. Within 30 minutes smoke started to issue from the nearby upcast Speculator shaft; within 1½ hours it had spread into 2 connecting mines. Various foremen and shift bosses rushed through the mine warning the men. A number of the men escaped through 3 connecting mines; 3 groups of men bulkheaded themselves from the fire (most of the men in 2 of these groups were saved—25 out of 29 in one place and 6 out of 8 in another), and 32 men were taken up from the Speculator shaft to safety. Of the 410 men in the mine, 163 perished, only 2 by direct contact with fire and the others because of gases from the fire. Soon after the fire started the Gem shaft fan was stopped to minimize the spread of gases through the mine. Shortly afterward fans at the Gem, Rainbow, and Speculator shafts were started as blowers, thus blowing approximately 100,000 cubic feet of fresh air per minute into the mine to clear the workings of fumes and force them up to the Granite Mountain shaft. Eventually the fire in the Granite Mountain was curbed with water, care being taken to keep this shaft an upcast. Fans were installed underground to aid the rescue parties, and about 48 hours after the fire started suction fans were placed in operation over the Granite Mountain shaft.

Rescue work was begun almost immediately. Employees of the North Butte Mining Co. and the Anaconda Copper Mining Co. with oxygen breathing apparatus began immediately to assist men to safety. A Bureau of Mines rescue car and crew arrived from Red Lodge, Mont., the day after the fire began. Twelve hours after the fire started 50 oxygen breathing apparatus were available, and for several days at least 30 apparatus wearers were employed on each shift. On the second morning after the fire the recovery workers were augmented by a second Bureau of Mines rescue car from Colorado, making additional rescue apparatus available; in all, 92 sets of rescue apparatus were used. Forty-eight hours after the fire started the Speculator shaft had been freed of gases from the fire, and the 2,400-foot level had been sufficiently cleared of smoke to permit rescue of the 25 live men out of the 29 behind the 2,471 bulkhead and recovery of 80 bodies. The recovery of 75 more bodies was difficult but was completed 8 days after the fire started. Several additional bodies were found afterward in cleaning up rock falls.

The following conclusions are derived from a study of this fire:

1. The upper end of an electric cable being lowered in a shaft should be firmly clamped, even if such clamping does ruin 8 or 10 feet of cable.
2. Electric cables in hoisting or ventilation shafts are a fire hazard, and boreholes should be used to bring such cables into a mine if practicable; if not, they preferably should be placed in upcast shafts or in shafts or shaft compartments that are as nearly fireproof as possible.
3. When a mine has two shafts and the one downcast is afire and filling the workings with smoke, efforts should be made by fans and other means to convert this shaft into an upcast.
4. The main hoisting shaft of every deep mine should be fireproofed.
5. Connections between mines should be closed with airtight doors held closed by a positive latch that can be readily opened from either side in an emergency.
6. To provide adequate ventilation and allow safe removal of men during a disaster, every mine should have at least two fully equipped shafts from the surface to the lower stoping level. All levels should be connected with both shafts.
7. Tight-fitting fire doors, preferably of fireproof construction, should be provided in every drift, crosscut, or other opening leading from any shaft. These doors should be of

the self-closing type with a latch or other means to prevent opening (if kept normally closed) by reversal of the air current.

8. Direction signs in as many languages as needed to be understood by the mine personnel should be posted at suitable points, indicating plainly the direction of escapeways.

9. Timbered shafts should have ample facility for quick-action fire protection; and waterlines for fire protection should be extended through mine workings, especially if much timber or other combustible matter is present.

10. Means should be provided for warning men promptly in an emergency.

11. Rescue apparatus is likely to be of great value in saving life and property if a serious mine fire occurs, such as that in the Granite Mountain shaft or the Argonaut shaft (described below). Men should be carefully trained to use such apparatus and to know its advantages and limitations.

Argonaut Mine Fire, Jackson, Calif.

A fire in the main shaft of the Argonaut mine in August 1922 killed 47 miners. This mine is a gold quartz property and at the time of the disaster employed about 165 men underground. It was worked through an inclined (57°) shaft that followed the dip of the vein 4,900 feet. The shaft had 3 compartments, each 4 by 5 feet, and was heavily timbered. Two compartments were used for skip hoisting; the manway contained a ladderway, a compressed-air line, a pump column, a high-tension cable, electric-light wires, and signal and telephone lines. Levels were driven at approximately 150-foot intervals. Ventilation was supplied through a second shaft 800 feet deep and offset raises connecting to the lower levels of the mine. This ventilation-raise system was equipped with ladderways from the bottom level to the surface. At the collar of the ventilation shaft was a nonreversible fan exhausting about 40,000 cubic feet of air per minute from the mine. Wooden doors directed the air in the downcast Argonaut main shaft to the lower levels.[8]

About 11 p. m. the shift boss and 2 skip tenders smelled smoke at the 4,200-foot level of the main downcast shaft and realized that there was a fire in the shaft above them. They had themselves hoisted to the 3,000-foot station and found 2 timber sets burning on the hanging-wall side just below the station. One of these men remained at the 3,000 station to observe conditions; the other two went in the skip through the fire to the 2,000-foot level, where they telephoned to the hoisting engineer, and then went to the surface to obtain means of fighting the fire. Soon after their arrival the mine telephone, signal system, and lights went out of order. The 47 men below were cut off. Smoke began issuing from the ventilation shaft and soon was backing up the main shaft. Men equipped with oxygen breathing apparatus entered the skip and futilely attempted to combat the fire. Changes in the fan housing to allow reversal of the air current would have taken several hours and probably would have been useless, as doors in levels above the fire zone normally closed would have been pushed open by a reversal of the air current and short-circuited the air; the air current was not reversed during the fire fighting. Exploration or rescue work through the ventilation raises was impracticable because 4 to 5 hours would be required for the men to climb back out of these raises, all in highly toxic air from the fire. Men wearing oxygen breathing apparatus controlled extension of the fire up the shaft by means of a high-pressure waterline and hose and then put in an airtight bulkhead about 2,300 feet down the main shaft. Access to the lower levels of the Argonaut mine could be gained by reopening caved connections with the adjoining Kennedy mine and driving some 80 feet in solid rock; 21 days of the most arduous labor opened a way to the 4,200-foot level of the Argonaut mine. Another connection from the 3,900-foot level of the Kennedy mine through 140 feet of solid rock was being driven at the same time as that on the 3,600-foot level but was not completed. Forty-six bodies were found on the 4,350-foot level behind a double bulkhead built of waste, boards, and clothing. Evidently gases had penetrated the bulkhead, and the men had died within a few hours after the fire. The 47th body was found later on one of the levels below the 4,350.

Three possible causes for this fire have been advanced: (1) Electricity; (2) incendiarism; and (3) lighted cigarette or match inadvertently thrown to the hanging-wall sets. Most of the investigators believed that a short circuit in the 2,300-volt powerline in the shaft caused the fire. The skip tender testified that during his observation the fire was spreading from about the location of the shaft wiring. The point of origin was near a cast-iron junction box, where the armor and outer insulation had been removed from the cable to allow it to enter the ends of the box. On the day before the fire some decayed timber just below the 3,000-station chute had been replaced. The old timber, stored temporarily in the manway, may have been thrown against the power cable, jarring or displacing the wiring at the junction box. A short circuit in the junction box or in the cable itself could have ignited trash in the chute or the stored punky timber. After the fire there was evidence of arcing about the cable at the junction box. The power cable comprised 3 smaller cables of 18 copper wires, each insulated with rubber and cotton fabric. The cable was encased in lead tubing, which in turn was armored, and the whole was protected from moisture by a covering of tarred hemp cord. A circuit breaker in the hoisting house was said to operate readily.

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[8] Pickard, B. O., Lessons From the Fire in the Argonaut Mine: Bureau of Mines Tech. Paper 363, 1926, 39 pp.

Advocates of incendiary origin of the fire pointed out that a previous fire in the mine had been proved of incendiary origin, that the fire spread very rapidly in heavy timbering, and that footprints had been discovered in a drainage tunnel below the shaft collar. Against this was the difficulty of anyone climbing 3,000 feet up the manway without discovery; moreover, other places in the shaft nearer the surface could have been fired more easily and probably with greater damage to the mine.

The following points stand out in this fire as a guide in preventing future loss of life in such circumstances:

1. Men in the mine should be warned immediately.
2. An attempt should be made to hoist them.
3. All underground doors that can be reached should be opened to short-circuit the air; or all of them, including those along every level, should be closed to confine the fire within the shaft and smother it.
4. The fan should be readily reversible.
5. Doors should be so hung and arranged to remain closed when air is reversed.
6. Stoppage of the fan is of debatable value; unquestionably, the natural draft of the fire in such an instance would reverse the normal downcast tendency of the Argonaut shaft.
7. Timbered shafts should be fireproofed or fire-protected or at least the timbered stations fireproofed. Particularly, the space around electrical devices and switches should be protected against fire.
8. Every mine should have an organization for preventing and controlling fires, as well as fire-fighting equipment and a good water supply immediately available.

Magma Mine Fire, Superior, Ariz.

A fire in the No. 2 shaft of the Magma mine, Magma Copper Co., about 3 a. m. November 24, 1927, caused the death of 7 of the 49 men in the mine at the time of the fire. The mine was developed by 5 shafts; No. 2 was 2,700 feet deep and Nos. 3 and 5 shafts 2,550 feet. Shafts 2, 3, and 5 were connected on the 2,550-foot and other levels. The No. 2 had 3 compartments, 2 for hoisting and 1 used as a manway; it also contained electric power and light lines.

Ventilation of the Magma mine at the time of the fire was directed by 3 surface and 3 underground fans, as well as various small blowers. An exhaust fan with a capacity of about 95,000 cubic feet per minute (c. f. m.) exhausted from No. 4 shaft but had been shut down a few minutes before the fire. Another exhaust fan at No. 1 shaft ventilated the upper levels of the mine. Shafts 2, 3, and 5 were intakes.

About 3:30 a. m. the fire in No. 2 shaft was discovered by the shift boss, who was investigating the continued steady ringing of the electric bells in both hoisting compartments of the shaft. He found smoke at the 1,200-foot level and by signaling with the pull bell was returned to the 500 level, where he carried the cage tender, who had been overcome by gas, through the ventilation doors and reported the fire. Shortly afterward a cage with one man on it was lowered; he died, presumably from burns or suffocation, and the cable was burned off. The men in the mine smelled smoke, and most of them proceeded to No. 3 shaft, where they were quickly hoisted. Some men came to the 2,200 station and saw the fire roaring up the shaft, but no smoke was coming out into the station. They were unable to attach a hose to the fire connection because it was at the shaft and in the fire.

The fire in the No. 2 shaft was controlled and eventually extinguished by streams of water turned down the shaft from two levels.

The No. 2 shaft had been gunited and concreted in part; but from the 1,600 level to the bottom it was timbered without fire protection, except at the stations, which were gunited to the 2,000 level. Guniting had been discontinued because of its stated tendency to promote and conceal timber decay. Gunited station timbering was fired during the shaft conflagration and continued to burn for days within the concrete shell after the main fire had been extinguished.

The fire evidently originated at or near the shaft at the 2,250 station, which was timbered and dry; the shaft timber was also dry. Oily waste at the car-repair station near the shaft ignited by a carbide lamp or possibly a cigarette butt was the origin of the fire; a transformer, a motor-driven fan, and light and power wiring, all at the 2,250 station, are also suspected.

The Bureau of Mines has drawn some 19 conclusions from this fire; the more important of which follow:

1. All main working shafts and stations, particularly downcast shafts or shafts in which men are handled, should be concreted or otherwise rendered fireproof or fire-resistant.

2. All electrical equipment should be placed in a fireproof location; if feasible, it should not be in or near shafts or shaft stations.

3. Stations and all workings should be kept clean of all flammable material, and refuse should not be allowed to accumulate in a mine.

4. Placing of waterlines on shaft stations, as was done at Magma, undoubtedly prevented much damage to the Magma mine. Connections for hose attachments, however, should be at least 50 feet from the shaft in order that they may be reached during a fire in the shaft.

5. Underground electrical wiring and equipment should be placed even more carefully than surface installations and should be inspected at least monthly by a competent electrician. Any defects should be remedied without delay.

6. If smoking is allowed underground it should be limited to prescribed areas in the mine where a minimum fire hazard exists; preferably smoking should not be permitted in dry timbered areas.

7. During the Magma fire the gunite definitely acted as a fire retardent. Even when the fire burned the gunite-timbered region, the progress of the burning appeared to be retarded to such an extent that there was a minimum of caving as compared with the large amount in ungunited timbered regions. If the No. 2 shaft had been entirely gunited or concreted and the station at the 2,200-foot level had been gunited, the fire might not have started.

8. It is dangerous to send men down on a cage when there is fire in a timbered shaft, even though the shaft is downcast. Fire may quickly climb up a downcast timbered shaft and convert such shaft into an upcast, even when the shaft is damp or fairly wet.

9. The escape of most of the 43 underground workers who came out alive is credited to the excellent ventilating system in the Magma mine; the foresight of the company in having 3 downcast shafts with hoisting equipment in them deserves high commendation.

As evidence that the improbable sometimes happens, 3 days after the fire in the No. 2 shaft started and when it was virtually under control, No. 1 shaft caught fire, although there was no possibility of fire being transmitted from the No. 2 shaft to the No. 1 shaft. This second fire apparently started from embers dropping down the shaft from a surface fire built near the shaft by a watchman on a cool night. This shaft contained no wiring or electrical equipment. Water could be turned into the shaft both from a water tank on the hillside just above the collar of the shaft and from the fifth level. The fire was controlled in a few hours. During the time it burned, however, there was considerable danger that the fire might reach the magazine, which contained 65,000 No. 8 detonators, in the 200 station near the No. 1 shaft. To avoid this, an oxygen breathing apparatus crew removed the detonators to the outside.

Glenn Mine Fire, Placer County, Calif.

A fire originated in some unknown manner in the wooden surface structures near the portal of the Glenn mine of the Capital Glenn Mining Co. on July 14, 1930, about 10:15 a. m. (fig. 3).

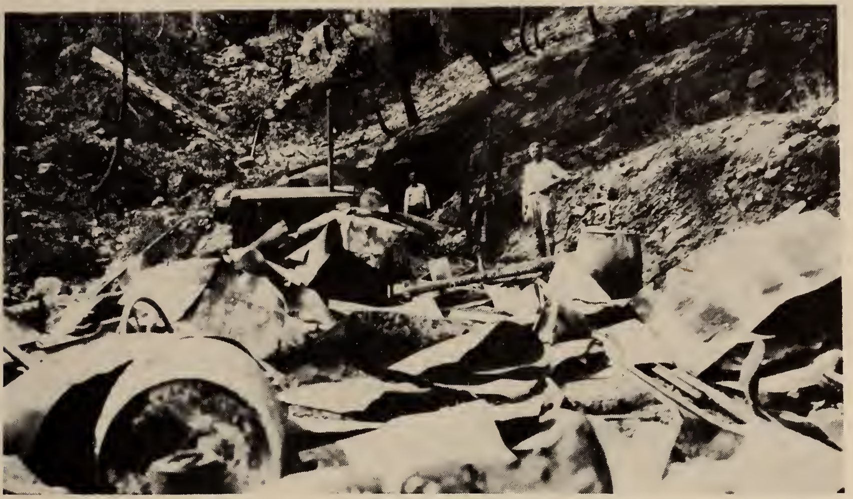

FIGURE 3.—Portal and Burned Buildings, Glenn Mine, California.

This mine was an underground placer property operated through adits driven into the hillside to recover the auriferous gravel from an old stream bed. The uppermost adit, the part of the mine then working, had been driven 1,121 feet from the portal; about 758 feet from the portal it connected with the middle or Moss adit by means of an incline dipping about 15°. The Moss adit was part of some old workings of a similar nature but was not kept repaired.

The ventilation was natural; fresh air entered the top adit at a velocity of nearly 200 f. p. m., followed down the incline, and left through the Moss adit and its connections.

The surface compressor house and shop building was about 25 feet from the portal of the upper adit, to which it was connected by a snowshed. The snowshed extended to the edge of the dump, connecting with the powerhouse about 75 feet from the end of this shed.

When the fire started no one was near the portal of the adit on the surface, and five men were working at the faces; these men tried to escape by going down the incline and out the Moss adit but were overcome and died in the attempt.

The fire burned all of the structures on the surface near the portal and about 70 feet of timbered adit inside the portal, jumped an untimbered gap of 63 feet, and ignited other timber sets; on account of the wetness of these sets, the fire died out when the timber at the portal was consumed.

No fire-fighting equipment was available at or near the mine, and equipment of the United States Forest Service was brought in to extinguish what was left of the fire.

Like many small properties, little or no consideration had been given to the possibilities of fire and its results; consequently no protection had been provided or plans made for combatting fire or preventing smoke from entering the mine.

Sunshine Mine Fire, Kellog, Idaho

The Sunshine mine fire occurred in December 1945 and resulted in a loss of 1 million dollars principally from loss of production and payment of direct costs in fighting the fire. The fire was confined to mined-out workings and was extinguished by sealing and flooding the lower levels. No injuries or loss of life occurred. The fire originated off the inclined shaft station on the 2,900-foot level when a short circuit in the battery-charging station set fire to the surrounding timbers. The fire started over the weekend when the mine was idle and was not discovered until Monday morning. The ventilating air current carried sparks for a distance of 300 feet along an untimbered drift; these ignited the connecting raise to the 3,100-foot level, which was heavily timbered. When discovered on the 3,100-foot level, the fire had reached major proportions.

Mine Fires in Foreign Countries

The greatest loss of life from metal-mine fires occurred in recent years in foreign countries, notably, the Braden Copper Co., Chile, South America, where 355 men were killed by carbon monoxide, and the Dolores mine, Argangueo Unit, American Smelting & Refining Co., Angangueo, Mexico, April 1953, where 35 men were killed by carbon monoxide.

The Dolores mine fire[9] started in a timbered raise and was believed to have been caused by sabotage, open lights, or smoking.

The fire disaster in Chile, South America, occurred when a drum of oil exploded in an underground blacksmith shop near the main portal, which was in intake air. A high concentration of carbon monoxide was carried to all parts of the mine within a few minutes.

CAUSES OF MINE FIRES

Most metal- and nonmetallic-mine fires may be grouped under the following headings:

1. Electric wiring and equipment.
2. Open lights, flame, and smoking.
3. Welding and cutting.
4. Spontaneous combustion.
5. Explosives and blasting.
6. Heating appliances.
7. Ignition of flammable dusts, gases, vapors, and liquids.
8. Incendiarism.
9. Miscellaneous.

ELECTRIC WIRING AND EQUIPMENT

The latest available data indicate that 55 to 65 percent of present-day metal- and nonmetallic-mine fires owe their origin to electricity. This percentage is likely to increase with the widening use of electric locomotives, pumps, hoists, blower fans, scrapers, drills, and like equipment. Some examples of fires caused by electricity follow:

1. A timber in a shaft gave way, breaking electric wires; timbers were ignited by an electrical short circuit.
2. Fire was caused by contact of a heated electric-light globe with some "dope" used for a belt.
3. A fire was caused by a spark from a short circuit in the hinge on a knife-type trolley switch.
4. The contact of a trolley wire with the cap of a sagging set of timber in a wet drift caused a smoldering fire, with dense smoke.
5. Fire was started by the contact of electric wires with 12- by 12-inch timber, probably due to defective insulation.
6. A small transformer and a starting compensator "ran hot," setting fire to a wooden frame.
7. A short circuit in the electric-power cable set fire to a timber in a wet shaft.
8. A fire was caused by an overheated resistance on an electric scraper hoist.
9. A trolley wire fell and heated, causing the insulation on the feeder wire to burn, and the burning insulation started a fire in the shaft. The ground was insufficient to operate the circuit breaker at the shaft.
10. Current was left on the controller of a hoist, the hoist motor became overheated, and the timber foundation began to burn.
11. The wiring at an electrically operated blower fan started a fire when squeezing ground caused short circuiting of the wires.

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[9] Bird, J. H., and McGuire, L. H., Report of Mine Fire and Rescue and Recovery Operations, Dolores Mine, American Smelting & Refining Co., Angangueo Unit, Angangueo, Michoacah, Mexico: Bureau of Mines unpublished rept., June 29, 1953, 210 pp.

12. An oil switch controlling the powerlines of a mine failed and started a fire at the shaft collar, which spread into the mine.
13. An overloaded trolley feed cable heated and caused a fire because the circuit breaker had been fastened in.
14. A scraper motor cable was damaged by a blast, and a short circuit started a fire.
15. An electric-light bulb set fire to a rubber glove at a timber raise.

OPEN LIGHTS, FLAME, AND SMOKING

Open lights (candles and later carbide lamps) have caused many mine fires. But the increased use of electric cap lamps has reduced the number from this source in recent years. It is estimated that 8 to 15 percent of all recent fires in metal and nonmetallic mines have been due to smoking, carbide lamps, and open fires or flames used for various purposes. This figure does not include fires started from welding and cutting. The causes of such fires are briefly given here:

1. A shaft fire was started by a carelessly thrown cigarette.
2. A miner going off shift threw a lighted piece of paper down a chute to see how much ore was in the chute, and a fire resulted.
3. A fire was started close to the fan motor on one side of a shaft station by contact between a miner's carbide cap lamp and canvas tubing taking air from the fan.
4. A match started a fire in a station close to a timbered shaft.
5. A pumpman burning newspapers on a concrete floor in a pumproom set fire to adjacent timber.
6. A candle used for illumination was left burning by a miner and caused a fire.
7. A fire was discovered in a raise at a point where spent carbide was thrown.
8. A mechanic's helper, while welding a water line, searched for a leak in an acetylene line with an open carbide light. The timber caught fire.
9. The open-flame lamp of a man who was recovering some tools that he had hidden where there was some dry lagging came in contact with the timber and caused a costly fire.
10. A lighted carbide lamp which a powderman placed on a shelf under a large fuse box ignited the paper between the boards and started a fire.
11. Mine officials inspecting some long-abandoned pillars of ore with a view to planning their removal sat down and smoked, and about 24 hours later a fire was giving off so much smoke that the mine had to be closed until the fire could be extinguished.

The fire hazards of open lights, smoking, and matches underground have led to the replacement of carbide lights by portable electric cap lamps and to restrictions on smoking. Although there are other good reasons for use of electric cap lamps, the reduction of the fire hazard has been the deciding factor in their adoption by a number of large mines. Other points regarding the use of electric lamps are discussed under illumination.

WELDING AND CUTTING

Available figures indicate that 12 to 20 percent of the recent metal- and nonmetallic-mine fires have resulted from welding and cutting operations. These fires occurred through the ignition of wood or other flammable material at the point were the torch was used or by pieces of hot metal dropping into timber or refuse below, particularly in timbered shafts. They usually smolder and are not discovered until they have made considerable headway.

The introduction and use of steel supports in underground mines, the welding and bonding of haulage rails, the practice of doing mechanical repair work underground, and the modern developments in welding and cutting technique have increased welding and cutting operations underground.

The following examples are typical of fires from this cause, which are now occurring in increasing numbers.

1. A blowtorch used to thaw a frozen water pipe in a shaft set fire to decayed timbers back of the pipe; the fire smoldered several hours and then flamed and was discovered.
2. Some steelwork was being removed from the collar of a shaft, and a small piece of hot metal lodged in the timbers some distance down the shaft; fire broke out after the crew had gone and destroyed the upper part of the shaft and the entire surface plant.
3. A shaft repair crew used a cutting torch, and a hot bolthead fell down the shaft and started a timber fire.
4. Electric welding and bonding of rails set fire to ties in a mine.
5. Sparks from cutting an old air line in a shaft caused a shaft fire.
6. Sparks from welding set fire to an accumulation of oil underneath an underground crusher.
7. A fire was started in the back blocking in which a crew had been cutting rails supporting the blocking.
8. A welder from a salvage company was cutting out the bolts from the sheave-wheel bearings over a shaft. The shaft collar was partly uncovered to maintain ventilation, and hot metal ignited the shaft timbers near the collar.

Information Circular 7453[10] describes 19 metal-mine fires from welding and cutting and points out precautions to be taken to prevent other fires from this cause.

Welding and cutting operations in shafts and underground will continue to increase, and fire-prevention measures must be taken to safeguard the areas and operations. The danger can be lessened by wetting down the areas, making fire extinguishers a part of welding and cutting equipment, providing an extra man to watch for falling hot material and incipient fires, thoroughly cleaning and inspecting the area when the job is completed, and leaving a man to patrol the area for at least 4 hours after the welding crew leaves.

SPONTANEOUS COMBUSTION

Burning is rapid combination of oxygen and some other element, usually carbon or sulfur, and it is possible for a fire to start without the application of flame or external heat. Such fires have occurred underground, although they are not common, and are very difficult to handle effectively. Where conditions permit rapid oxidation and the heat so produced is not dissipated, the temperature may rise to a point at which actual burning takes place. The materials oxidized most readily are oily or greasy waste, hay, manure, carbonaceous shales, and sulfide ore. If oily waste is not confined, spontaneous combustion is probable. Punky or rotted wood is easily ignited, especially if finely divided. Occasionally, spontaneous fires are reported as having started from the oxidation of timber, but it is unlikely that solid or standing timber will ignite spontaneously unless some more readily oxidized substance is present. Sulfide ores, especially certain types, oxidize rapidly when they are in a fine state of subdivision and will burn if in close contact with burning timber. Caved material and old fills containing crushed or broken sulfides and timber present a serious fire hazard where oxygen is supplied by currents moving too slowly to dissipate the heat. Massive sulfide ore in place will rarely burn; sulfide ores, particularly copper and iron sulfides, may fire when in moving ground where they are crushed.

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[10] Look, Allen D., Underground Metal-Mine Fires From Cutting and Welding: Bureau of Mines Inf. Circ. 7453, 1948, 9 pp.

Carbonaceous shales not only burn by spontaneous combustion but also ignite timber or other combustible material. They are most dangerous as a fire hazard when they contain pyrite or marcasite and are in moving ground. Spontaneous fires in sulfide ores or in shales rarely develop rapidly enough to cause loss of life, but their control may cost large sums of money and occasional loss of life. The exclusion, so far as possible, of sulfides from stope filling and the early removal of broken sulfide ore are advisable precautions. Adequate ventilation to dissipate heat and thereby prevent rise of temperatures in stopes having broken sulfide ore is another practical precaution. Where a fire has started but has not developed to any considerable extent, it may be practicable to load out the burning material; if not, sealing off or in a few instances slime filling of the fire area is the method used to check and limit the extension of the fire. A fire may develop in filled ground without apparent heat manifestations; such fires are very difficult to extinguish or to handle with a reasonable degree of effectiveness.

Four to twenty percent of the metal- and nonmetallic-mine fires are attributed to spontaneous combustion, depending largely upon the type of ore mined.

EXPLOSIVES AND BLASTING

A number of instances are on record of explosives, fuse, and blasting starting fires in mines. Capped fuses spit and thrown into abandoned timbered areas have started fires. Blasting of cribs or posts in top-slicing or in cut-and-fill stopes has caused costly mine fires. Some posts caught fire from the fuse when they were blasted out in a mine using a caving system, and before the fire could be brought under control the whole mine had to be flooded. In another instance a jute sample bag was left where a spit fuse came in contact with it and started a fire. This mine now uses fire-resistant sacks for samples as well as explosives. Heavy blasting has been known to start fires and in a few instances dust explosions in high-sulfide ore when fine dust from the ore has been ignited by flame from explosives.

HEATING APPLIANCES

Heating appliances frequently cause mine fires in surface buildings and underground. Fires have started from small heating stoves or from heating units of all kinds, including electrical devices, used to warm oil or lunches, to dry clothing, or to heat underground stations or surface structures. Blacksmith forges, air reheaters, and steam pipes in contact with timber have started fires. A defective burner in a drying plant at a mine clogged and flared, setting fire to the plant building, which burned completely despite efforts to extinguish it. One metal mine had 3 fires in surface buildings in 5 months due to oil heaters not in proper working order. Electric heaters used underground cause fires when they are placed too close to wooden partitions or timbers.

IGNITION OF FLAMMABLE DUSTS, GASES, VAPORS, AND LIQUIDS

Accumulations of methane mixed with air in explosive proportions have been ignited in mines and tunnels in many sections of the United States. These ignitions have caused injury to workers but have not caused fires, except in tunneling operations where extinguishment was easy. This subject is discussed under Gases in Metal and Nonmetallic Mines.

The ignition of iron-copper sulfide dust and gilsonite dust is discussed under Explosition Hazards in Metal and Nonmetallic Mines.

The increasing use of diesel-powered engines in metal and nonmetallic mines presents a hazard from flammable liquids and vapors in handling fuel oil underground. There have been a number of ignitions.

One of the most serious hazards at mines where electric power is not used is the ignition of vapors when gasoline is transferred from containers to the fuel tanks of gasoline-powered hoists, compressors, or power units. These fires occur most frequently at mines in outlying districts or small operations where gasoline engines find favor; vapors from the pouring of gasoline are drawn by air currents to an open flame, resulting in a fire that usually destroys the building and equipment.

INCENDIARISM

Actual records of incendiary fires are comparatively few, although some of the fires listed as originating from an unknown source are thought to have been due to this cause. A compilation made by the Bureau of Mines in 1923 listed 2 fires with deaths of 13 men as of incendiary origin, and in the period 1940–44, 1 metal-mine fire was listed as due to that cause. The Dolores mine fire was attributed possibly to sabotage, open lights, or smoking.

MISCELLANEOUS

Fires have been started from unusual sources. In one instance the sparks from a railroad locomotive set fire to the wooden headframe on the surface. Hot embers from the headframe fell into the shaft, and the timbering of the shaft was consumed by fire. In another instance spent carbide dumped into metal cans was emptied into the shaft pocket, and two or three cars of ore were dumped on top of it; ignition of the timber lining resulted. Lightning started one fire by striking the cables leading to the electric pump; the high voltage burned out the control in the underground pumproom and set fire to the wooden panel and supporting timbers.

Nine percent of the fires listed in table 2 are ascribed to unknown causes.

CONTROL AND EXTINGUISHMENT OF MINE FIRES

FIRE-FIGHTING EQUIPMENT

Every necessary precaution should be taken to prevent underground fires. Fire-fighting equipment and facilities should be provided both underground and on the surface. Crews should be trained to effectively combat all fires. Underground personnel are always endangered by surface-plant fires; their safety and to a lesser degree the preservation of property make fire prevention a most important function of every mine safety organization.

Many fires have been extinguished in the incipient stage by direct attack with water, chemicals, or other smothering materials. Where possible, this method is most desirable. Failure to extinguish fires by direct method is generally due to late discovery; lack of water or other materials, equipment, or essential facilities; or improper procedure in the early stages, which permits the fire to get beyond control.

Common methods of control are:

1. Direct attack with water, chemicals, or other materials.
2. Enclosing the fire area with tight seals or bulkheads.
3. Introducing inert gas, such as carbon dioxide, into the fire area.
4. Flooding the mine or affected area with water.
5. Flushing the affected area with silt or other solid material conveyed with water.

WATERLINES AND WATER SUPPLY

An adequate water supply and a well-laid-out distributing system are needed for the protection of mining plants against loss by fire. Fire hydrants should be placed at key places inside principal buildings, but, even more important, some should be available at such distances from buildings that a fire would not prevent their use. A standard fire stream is generally recognized as 250 gallons per minute (g. p. m.), with a 1⅛-inch nozzle and a pressure of 45 pounds per square inch at the nozzle; at least 2 such fire streams should be available for important structures in an emergency. The friction loss of water flowing in pipes is higher than is generally realized; with a flow of 500 g. p. m., sufficient for 2 fire streams, the friction loss per 1,000 feet in a 6-inch pipe is 15 pounds per square inch (p. s. i.), in a 4-inch pipe 100 pounds, and in a 2½-inch pipe 1,020 pounds. To deliver 2 standard fire streams through 1,000-foot lengths of such pipes, the initial pressures would need to be approximately 60, 145, and 1,065 p. s. i. If water at an initial pressure of 45 p. s. i were taken through 1,000 feet of 6-inch pipe and discharged as 2 standard fire streams, the flow would be about 216 g. p. m. for each stream at a nozzle pressure of approximately 33.7 p. s. i.; if the pipe were 4 inches in diameter, the flow from each nozzle would be about 133 gallons and the discharge pressure 12.6 p. s. i.; if 2½-inch pipe were used, the flow would be reduced to about 45 gallons at a nozzle pressure of approximately 1.5 p. s. i. These flow volumes and pressures are calculated from the Fire Stream Tables of the National Bureau of Fire Underwriters; no allowances are made for hose losses.

Connecting fire mains to form a loop or circuit to eliminate dead ends is always recommended.

The water supply should be ample to maintain hose streams which might be used for 40 or 50 minutes. Thus, two standard fire streams (500 g. p. m.) could discharge 25,000 gallons during the period that effective fire fighting would ordinarily be accomplished. Where pumping systems and mine drainage can be utilized, the time for which the hose streams can be supplied is extended. Where water supplies are limited and installations small, effective fire fighting can be done by judicious use of the waterlines available; but the handicaps are great, and the protection is limited. The cost of a satisfactory water system for fire protection is justifiable only where the value of buildings and contents warrants the expenditure, but fortunately most metal-mine plants require waterlines for mill supply or mine drainage so that provisions for fire protection can be made at moderate cost. Sprinkler systems in mine plants, as well as in timber shafts, deserve more consideration than has been given them.

Underground waterlines in shafts and shaft stations and on important levels should be connected to suitable surface storage and have suitable valve control and adequate pressure. These lines should be at least 2 inches in diameter, and hose of adequate length should be quickly available at any point. Connections should be maintained in readiness for instant use, and any necessary special tools or fittings should be kept at a well-marked place where they may be used. Air lines should be convertible into water lines, and the location of valves or prepared connections to accomplish the change should be marked and full instructions for making the change given to shift bosses and pipemen (fig. 4).

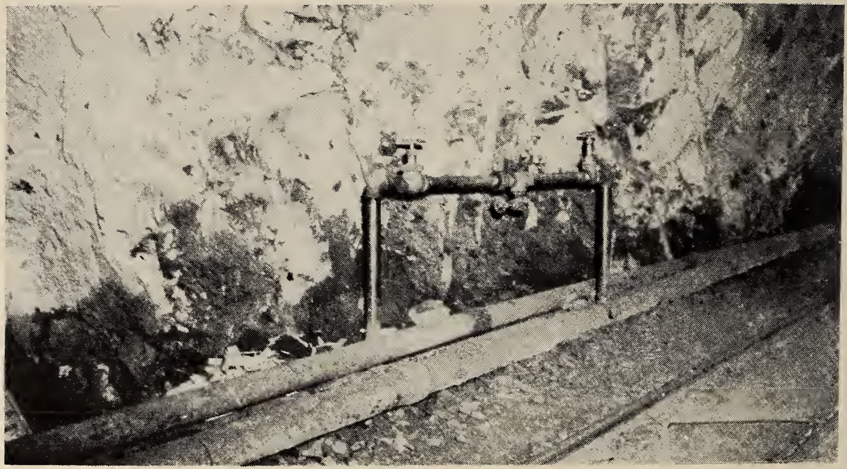

FIGURE 4.—Bypass to Convert Air Lines to Water Lines for Fire Fighting.

Tests with hose and fire streams used under the conditions usual to mine workings[11] showed that 45 p. s. i. is the most effective pressure for mine-fire fighting. In deep mines reservoirs or tanks are usually installed at different stages to prevent excessive pressure at the hose lines; in some instances regulating pressure valves are used. The recommended maximum pressure for fire fighting is about 100 p. s. i. even with a 1½-inch hose, as higher pressures make handling of the hose difficult; a 2½-inch hose in mine workings may prove too heavy to be handled readily. Waterlines used for drilling usually require pressures of 80 to 100 pounds and in most mines are used for fire fighting. The hydrant pressure of firelines should also be regulated by the length and size of hose and nozzle and whether the hose is to be handled by a crew or by one man. Reports from Bureau of Mines engineers show that underground installations for fighting fire at several large, well-equipped mines are as follows:

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[11] Tracy, L. D., and Hendrix, R. W., Small Hose Streams for Fighting Mine Fires: Bureau of Mines Tech. Paper 330, 1925, 23 pp.

Large iron-mining company, operating 7 underground mines.—Waterlines extend to the top of all shaft headframes, and most of these are equipped with sprays that can be operated from the surface. All main drifts and crosscuts are equipped with waterlines (2- to 4-inch standard size) with gate-type valves and hose connections every 100 feet. Air lines (4-inch minimum) are cross-connected with water lines to permit a supply of water to all working places. At least one underground fire truck is maintained at each mine. All surface plants are equipped with standard fire hydrants, and at least 500 feet of hose is kept under cover nearby.

Large magnetic mine.—Tanks and reservoirs with a capacity of 500,000 gallons supply water at approximately 90 p. s. i. to a 6-inch looped circuit with adequate and well-placed hydrants; 2½-inch hose, nozzles, adapters, and wrenches are available at every hydrant.

Large copper mine.—Shaft is equipped with 3-inch dry pipeline and each shaft station with 2½-inch standpipe; hose is kept on surface. Drilling-water lines on levels, 2-inch and 1-inch, have spud connections for ¾-inch and 2-inch mine hose at 100-foot intervals; pressure in line is 100 to 175 p. s. i. Air- and water-line connections are provided. At ordinary times, especially in winter, pipelines in shafts must be kept dry to prevent freezing.

Large copper mine.—Water outlets and mine hose lengths are provided at shaft stations, with mine hose connections at intervals throughout mine; line pressure is about 165 p. s. i. Air- and water-line connections are provided.

Large copper mine.—Shaft is equipped with sprays, and standpipe and hose are provided at shaft stations. Fire trucks are equipped with 1½-inch hose and nozzle, an extra 1½-inch revolving nozzle, and other tools and fittings.

Large copper mine.—Sprays in shaft are used daily. Drilling-water lines have hose connections throughout mine; pressure at shaft stations is 150 to 200 p. s. i. Air- and water-line connections are provided.

Large metal mine.—A 1,000-gallon tank with a capacity of 100 g. p. m. at 80 p. s. i. is mounted with motor and pump on mine flatcar.

SPRINKLERS

Where it can be applied, the automatic sprinkler is one of the most important fire-protection devices.[12] A fine spray of water applied to heated material or to spreading fire will prove effective immediately unless the fire has gained tremendous headway. Sprinkler systems are used most widely to protect buildings but have been applied successfully to such installations as electric substations and transformers and fuel-oil tanks. This type of protection could be used to a much greater extent at mine properties, particularly in shaft protection. Even where mine buildings are of temporary, low-cost construction and their contents have only a moderate value or importance to operation, control and extinguishment of fire are still necessary to avoid the loss of more vital buildings and the spread of fire and smoke into the mine. If water supplies are not available or another extinguishing agent is preferred, one of the special extinguishing systems employing foam, carbon dioxide, steam, or mixtures of inert gases can be used.

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[12] Crosby-Fiske-Forster, Handbook of Fire Protection: Nat. Fire Protect. Assoc., 1941 ed., pp. 719–976.

Some mining companies have installed pipelines in timbered shafts placed to sprinkle every square foot of the main shaft and shaft stations. An installation at the Copper Queen mine is described[13] as consisting of pipelines which are laid down the shafts and carry water to sprays set under the timbers at 25-foot intervals. The water is turned on from the surface. To prevent changing the air direction in an upcast shaft by the introduction of water, thus carrying smoke upon men, compressed-air-controlled doors on the various levels are first closed. Another mine[14] installed sprinkler rings throughout the timbered shaft, with water control at the surface.

Automatic sprinkling systems as employed for protecting buildings have been suggested for underground and shaft use and possibly have been adopted in a few mines. The possibility of water freezing in shaft installations must be considered.

While assistant general manager of mines of the Anaconda Copper Co., Daly,[15] in discussing mechanically ventilated mines, stated "In case of fire the smoke and gases are quickly drawn through the mine, and the only safeguards are fireproofed shafts, surface buildings, tunnels, and electrical installations."

FIRE EXTINGUISHERS

A fire may often be checked and extinguished while still in the incipient stage by using a suitable fire extinguisher. Extinguishers should therefore be placed at important points both in the surface buildings and underground.

Three general classifications of incipient fires have been developed by Underwriters' Laboratories, Inc., in accordance with the origin and/or material burned. Fire-extinguishing devices approved by Underwriters' Laboratories, Inc., and other recognized bodies are appropriately designated for suitability by a metal plate bearing letters corresponding to the following fire classifications:

Class A fires.—Fires in ordinary combustible materials such as wood, paper, textiles, and rubbish. The quenching and cooling effect of quantities of water or solutions which contain water as the main ingredient are of first importance in extinguishing these fires.

Class B fires.—Fires that involve inflammable liquids, greases, and other petroleum products and rubber and rubberlike materials. A blanketing or smothering action with chemical or mechanical means is of primary importance in extinguishing fires in this class. Solid streams of water tend to spread the fire, but under certain circumstances water fog nozzles prove effective.

Class C fires.—Fires that occur in or near live electrical equipment. When fighting these fires, it is of utmost importance to use nonconducting extinguishing agents. Carbon tetrachloride, carbon dioxide, or dry chemicals have a blanketing of smothering effect on electrical fires in switchboards, motors, and other electrical equipment. A solid stream of water should not be used on class C fires.

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[13] Sherman, G., Measures for Controlling Fires at the Copper Queen Mine: Trans. AIME, vol. 59, 1918, pp. 318–325.

[14] Bruce, J. L., Fire Prevention in Butte and Superior: Min. and Sci. Press, vol. 118, 1919, p. 752.

[15] Daly, W. B., and Berrien, C. L., Mining Methods and Installations of Anaconda Copper Mining Co. at Butte, Mont.: Trans. AIME, vol. 68, 1922, p. 6.

In addition, upon the metal tags are stamped numbers which show the number of extinguishers necessary to form one unit of first-aid, hand fire protection.

Class A Extinguishers

Class A extinguishers should be used on ordinary combustible fires only. They include:

1. Soda-acid extinguishers.
2. Pump tank extinguishers.
3. Gas-pressure extinguishers.

Soda-acid extinguishers are the most common type in which water is expelled by pressure. Pressure in this extinguisher is built up by chemical action of sodium bicarbonate and sulfuric acid. The sodium bicarbonate (baking soda) is dissolved in the water when the container is filled. The sulfuric acid is contained in a loosely stoppered glass bottle at the top of the extinguisher.

When the extinguisher is turned upside down, the stopper in the glass bottle drops out and the sulfuric acid mixes with the sodium bicarbonate solution. The resulting chemical reaction produces carbon dioxide, which builds up enough pressure to expel the water through the hose.

Soda-acid extinguishers should be recharged immediately after use or annually. Where the water in the extinguisher may freeze, a heated cabinet should be provided. Since the chemical action is affected by cold weather, antifreeze agents should not be substituted for the heated cabinet. They also may cause corrosion, reduce the extinguishing action, or impede the chemical reaction.

Pump tank extinguishers are comparatively simple in construction. The tank itself contains 2½ to 5 gallons of water. The water is expelled through a hose and nozzle by means of a hand pump. Although tank extinguishers are usually equipped with a handle for carrying, some are designed to be carried on the back.

If these extinguishers are exposed to freezing temperatures, calcium chloride and a rust inhibitor should be added to the water to prevent freezing. Common salt or other chemicals not recommended by the manufacturer should not be used. They may corrode the tank or form undesirable solutions that may reduce the extinguishing action. Pump tank extinguishers should be inspected frequently. Make certain they are filled to the required level. Check the tank for corrosion. Oil the pump occasionally to make certain it will work freely.

Gas-pressure extinguishers are similar to the soda-acid extinguishers in that water is expelled by pressure. Pressure is supplied in this unit by carbon dioxide gas. The gas is contained in a cartridge, which is punctured when the extinguisher is turned upside down and bumped on the floor or other object.

Gas-pressure extinguishers should be inspected at least annually. The gas cartridge should be weighed to make certain that no gas has escaped. If it has lost more than one-half ounce in weight it should be replaced. The cartridge may be charged with calcium chloride to prevent freezing. Use only calcium chloride and gas cartridges recommended by the manufacturer. Make certain that the liquid is at the required level.

Class B Extinguishers

Class B extinguishers should be used on fires involving flammable liquids. However, they may also be used on class A fires. They include:

1. Loaded-stream extinguishers.
2. Foam extinguishers.

Loaded-stream extinguishers operate similarly to soda-acid and gas-pressure extinguishers; however, instead of water, an alkali-metal salt solution is used. If chemical reaction is the expelling force, the extinguisher is operated by inverting and permitting acid to mix with the alkali-metal salt solution. If carbon dioxide cartridges are used, the extinguisher is inverted and bumped. In either instance, the manufacturer's instructions for recharging should be followed.

If operated by chemical reaction, the extinguisher should be discharged at least annually. The extinguisher and hose should be washed thoroughly before recharging. If gas cartridges are used, they should be weighed at least annually, and if the cartridge has lost more than one-half ounce in weight it should be replaced.

Loaded-stream extinguishers have proved effective in combatting conveyor-belt fires. They also tend to make fire-retardant the flammable materials sprayed by the stream from the extinguisher.

Foam extinguishers are similar in operation to soda-acid units. Sodium carbonate and a foam-stabilizing agent are dissolved in water before the container is filled. An aluminum sulfate solution is placed in a smaller inner container. The solutions mix when the extinguisher is turned upside down. Carbon dioxide gas is formed and expels the foam, which forms a stiff, closely knit mass that floats on a burning liquid and smothers the flames.

Foam extinguishers are most effective on class B fires contained in tanks or vats. They are not as effective on burning liquids that are flowing. Foam should be directed on the sides of tanks or vats so that it will flow over the surface of the liquid.

Foam should not be used on fires involving alcohol, ethers, esters, lacquer thinners, acetone, or carbon disulfide. If applied to hot flammable liquids, it may cause boiling and become ineffective. To effectively combat fires of these liquids, carbon dioxide and dry-chemical extinguishers should be used in conjunction with the extinguishers to cool these liquids and their containers. Water sprays may also be used for this purpose.

Foam extinguishers should be protected from freezing with a heated cabinet. No antifreezing solutions should be used, and the unit should not be exposed to high temperatures.

Foam extinguishers should be recharged after using or annually and washed thoroughly with water before recharging. Solutions should be mixed accurately and thoroughly.

Class C Extinguishers

Class C extinguishers should be used on electrical fires; however, they may also be used on class B fires. They include:

1. Vaporizing-liquid extinguishers.
2. Carbon dioxide extinguishers.
3. Dry-chemical extinguishers.

Vaporizing-liquid extinguishers contain a nonconducting liquid, usually composed largely of carbon tetrachloride, as the extinguishing agent. The extinguishing agent resists freezing at temperatures as low as −50° F. It also resists rust and corrosion.

Three methods are employed to expel the extinguishing agent:

1. Pump-type extinguisher in which the agent is expelled by operating a hand pump.
2. Stored carbon dioxide type in which carbon dioxide expels the vaporizing liquid. These extinguishers are equipped with pressure gages to detect any loss in pressure. Some extinguishers use carbon dioxide cartridges, which should be weighed at least annually to check leakage.
3. Compressor-air type in which pressure may be built up with a pump or supplied by compressed-air lines. These are equipped with pressure gages.

The extinguishing action of the vaporizing-liquid extinguisher is produced when the liquid comes in contact with the fire and forms a smothering vapor. The vapor is heavier than air and blankets the fire.

Carbon tetrachloride involves toxic hazards if the extinguisher is used in a small or poorly ventilated area; it may also present hazards if unusually large quantities are used. However, there is little danger of toxic hazards when units are used outdoors and in large, well-ventilated areas.

Although vaporizing-liquid extinguishers are most effective on electrical fires, they may also be used on small class B fires; however, they are not efficient on class A fires, since plain water has approximately 10 times the cooling effect.

These extinguishers should be inspected at least annually. They should be partly discharged and refilled with fresh liquid. Only the liquid recommended by the manufacturer should be used. Commercial carbon tetrachloride should not be used because of its corrosive action and because it freezes at −8° F.

Carbon dioxide extinguishers contain liquid carbon dioxide under pressure. The unit itself consists of a steel-walled cylinder, a valve for releasing the carbon dioxide, and a tube designed to effectively direct the carbon dioxide. The tube extends to the bottom of the tank so that only liquid carbon dioxide will reach the discharge horn, which is so designed that no air can enter the stream of carbon dioxide when its velocity is high.

When the carbon dioxide leaves the horn, it is chilled by expansion, and approximately one-third becomes “snow” or solid carbon dioxide. Because of the low temperature, this solid and the inert gas tend to prevent flashback and smother the fire.

Carbon dioxide not only smothers the fire, but it is a nonconductor of electricity and leaves no residue. Toxic hazards are slight, except when extremely high concentrations are used for long periods.

When a carbon dioxide extinguisher is used, the stream should be played first at the edge of the fire and then slowly moved from side to side. As the flames are smothered the stream should be gradually moved forward.

Carbon dioxide extinguishers should be inspected at least annually. They should be weighed to detect any loss in weight. If the loss is 10 percent or more, the extinguisher should be recharged, preferably by the manufacturer.

Dry-chemical extinguishers contain an extinguishing agent, generally sodium bicarbonate, which has been treated with other chemicals to make it free-flowing and water-repellent. The extinguishing agent is expelled by a carbon dioxide cartridge or nitrogen. Carbon dioxide cartridges are used in smaller units, whereas nitrogen in cylinders is used in larger ones. Capacities of dry-chemical extinguishers range from 4 to 30 pounds.

When dry chemicals are played on fires, carbon dioxide and water vapor are released, tending to smother the fire. A fine coating of the chemical also covers surrounding material. These extinguishers are most effective on electrical fires, liquid fires, and flash fires from textile lint.

Carbon dioxide cartridges should be weighed at least annually to detect any loss in weight. Cartridges that require recharging preferably should be returned to the manufacturer. Only dry chemicals and cartridges recommended by the manufacturer should be used.

General Characteristics of Portable Extinguishers

The types, capacities, rating, ranges, and discharge times for portable fire extinguishers are given in table 4.[16]

TABLE 4.—*Portable fire extinguishers*

Type of extinguisher	Capacity	Rating	Horizontal range (feet)	Discharge time (seconds)
Soda-acid	1½ gallons	A-2	30–40	35
	2½ gallons	A-1	30–40	60
Pump tank	2½ gallons	A-2	30–40	60
	5 gallons	A-1	30–40	120
Gas-pressure	2½ gallons	A-1	30–40	50–60
Loaded-stream	1 gallon	A-2, B-4	30–40	35
	1¾ gallons	A-1, B-2	30–40	45
	2½ gallons	A-1, B-2	30–40	60
Foam	1½ gallons	A-2, B-2	30–40	35–40
	2½ gallons	A-1, B-1	30–40	60
	5 gallons	A-1, B-1	30–40	60
Vaporizing-liquid	1 quart	B-2, C-2	20–30	45
	1½ quarts	B-2, C-2	20–30	70–80
	2 quarts	B-2, C-2	20–30	150
	1 gallon	B-2, C-1	20–30	60–90
	2 gallons	B-2, C-1	20–30	100
Carbon dioxide	2 pounds	B-4	3	13–18
	4 pounds	B-2, C-2	4	15–26
	10 pounds	B-2, C-1	6	20–45
	15 pounds	B-1, C-1	6	25–45
	20 pounds	B-1, C-1	8	25–60
Dry-chemical	4 pounds	B-2, C-2	5–12	8
	15 pounds	B-1, C-1	20–25	15–25
	20 pounds	B-1, C-1	20–25	20–25
	30 pounds	B-1, C-1	20–25	20–30

Use

Fire pails and water barrels are employed for extinguishing small fires both on the surface and underground. Water or antifreezing solution is kept close to exposed locations. Their use is limited to fires that may be readily reached by liquids thrown or poured from a pail.

Sand or other pulverized incombustible dust is commonly used to prevent fires by covering or absorbing spills of flammable liquids; sand or dust is also effective in extinguishing fires in small quantities of flammable liquids and grease. Use of sand or incombustible dust on other fires is limited to the smothering action that can be attained; it may be necessary to cover the burning material completely. The powdered material should be applied with a spreading motion from a scoop or the container. Sand or incombustible dust used on electric motors might cause damage that could be avoided by use of another type of extinguisher.

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[16] Bureau of Mines, Accident Prevention in Nonferrous-Metal Processing Plants. 2. Mills and Concentrators: 1954, 380 pp.

The portable extinguishers that have been discussed are of value only for incipient fires, and it will be noted that each type has certain advantages and disadvantages. In installing portable extinguishers at points in or about a mine these relative advantages and disadvantages should be weighed in deciding upon the type of extinguisher to be installed.

FIRE TRUCKS

Fire trucks carrying pressure tanks, hand extinguishers, hose, gas masks, fans, and other accessories have been built to fit on cages and go to any part of the workings. In some mines trucks fitted with tanks which take pressure from the compressed-air line are kept on the main levels, where they can be quickly moved to important points (figs. 5 and 6).

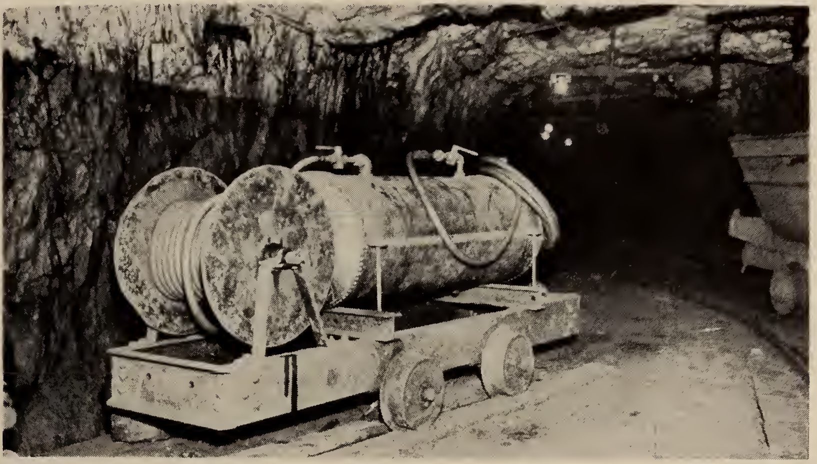
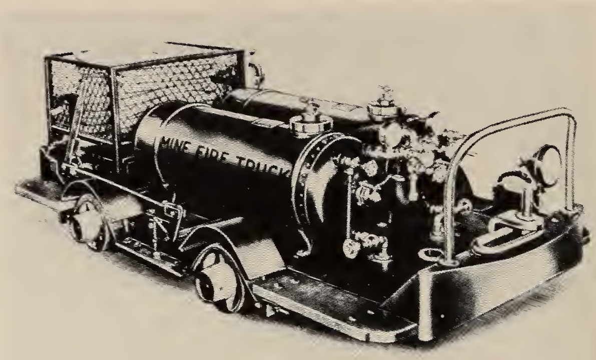


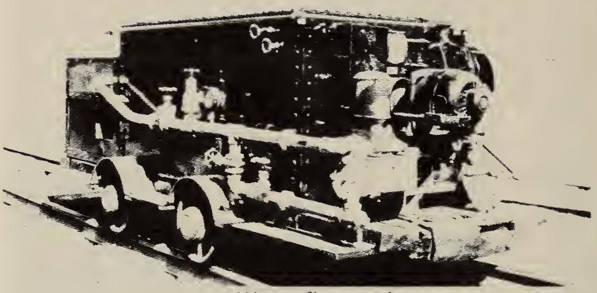
Figure 5.—Mobile Fire-Fighting Equipment.

Fire trucks for protecting surface structures may range from wheeled hose reels to motor-driven pumping equipment. A number of light trucks and trailers have been designed and built for use in communities and industrial plants; hence, a suitable type is available for almost any situation. To furnish effective service such equipment must be kept in readiness for instant use, and persons who have had some practice with the equipment must be at hand when it is needed.

In addition to water outlets and mine hose lengths at shaft stations, mine hose connections at intervals throughout the mine, and a line pressure of approximately 60 p. s. i., one large lead and silver mine in Idaho is equipped with a 500-gallon water tank, mounted on trucks, for providing foam between any two levels of an inclined shaft. The



Chemical fire truck



Water fire truck

FIGURE 6.—Mine Fire Trucks.

foam-extinguishing equipment is tested regularly and is kept at the top station for emergency use. The valve is turned on at the level above the fire, and the truck is lowered slowly through the fire to the level below, leaving a thick foam on the four sides of the shaft lining.

FIREWALLS

The spread of fire between closely adjoining buildings or from one part of a building to another part may be limited by firewalls. Such walls may check a strong fire so that it can be extinguished or held to one place or allow time to salvage equipment or material from adjoining places. Firewalls may be of any solid, fireproof material, or they may be constructed of timber studding covered with shiplap or other tight boarding and completely surfaced with fireproof material. If plasterboard or transite sheets are used to face such walls, the cracks should be thoroughly covered with overlapping strips. Firewalls should extend at least 3 feet above the roof and should have approved fire doors on each side of the wall. Places where firewalls might be advisable at mine plants are large warehouses, combination change rooms and supply houses, conveyor sheds with mill buildings and crushing plants, and adjoining garages and shops.

PROTECTIVE EQUIPMENT AND METHODS

Under abnormal conditions, as during mine fires, after mine explosions, during interruptions in ventilation, or after blasting, poisonous or asphyxiating gases, such as carbon monoxide, and atmospheres depleted of oxygen may be encountered. To fight mine fires or to seal or unseal them, to carry on recovery work speedily and safely, and to aid men trapped in a mine under such conditions, it is essential that means of protection against gases be provided.

The Bureau of Mines has tested and approved various types of gas masks [17] under schedules that set forth the minimum requirements gas masks should meet to be safe and satisfactory for use in industry.

GAS MASKS

A gas mask used underground in fire fighting should be of a type that protects fully against carbon monoxide, the gaseous product of incomplete combustion.

The universal gas mask approved by the Bureau of Mines protects the wearer against all gases and vapors that commonly occur in mines and against dusts, mists, fogs, and smoke, provided that the percentage of all such gases and vapors does not exceed 2 and that the air surrounding the gas-mask wearer contains enough oxygen to support life. It must be remembered that the gas mask furnishes to the wearer only filtered air from the surrounding atmosphere and of itself gives the wearer no life-sustaining oxygen as contrasted with the oxygen breathing apparatus, which does furnish oxygen. The sufficiency of oxygen in the air may be tested with the flame of a candle or flame safety lamp; if the flame "goes out," the air is not safe for use of a gas mask. The flame of a carbide lamp is not as satisfactory as that of the flame safety lamp for testing because the carbide flame may burn in air containing 12 or 13 percent oxygen, and air containing so little oxygen may affect or endanger a gas-mask wearer. The flame of a safety lamp is extinguished in air containing 16 to 17 percent oxygen.

The essential parts of the universal gas masks, some of which are shown in figure 7, are a full facepiece connected by a flexible breathing tube and timer to a canister, which is held in place on the wearer by a canister harness. The canister contains the materials for purifying the air drawn through it. The weights of complete universal gas masks range from 5 to 6½ pounds. The facepiece covers the entire face, is comfortable to wear, and permits breathing through both the mouth and the nose. A wearer may converse with others nearby, although the voice is somewhat muffled. The inhaled air enters the facepiece through tubes, which discharge it against the eyepieces and thus lessen the tendency of the eyepieces to fog. The exhaled air passes out of the facepiece through an exhalation valve.

Although all the air entering the facepiece passes over the inner surface of the eyepieces, under some conditions moisture may accumulate on the eyepieces and thus reduce visibility. To minimize the effect

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[17] Forbes, J. J., and Grove, G. W. (revised 1954 by Walker, W. D., Jr., Pearce, S. J. Morrow, A. E., and Berger, L. B.), Protection Against Mine Gases: Bureau of Mines Miners' Circ. 35, 1954, 58 pp.

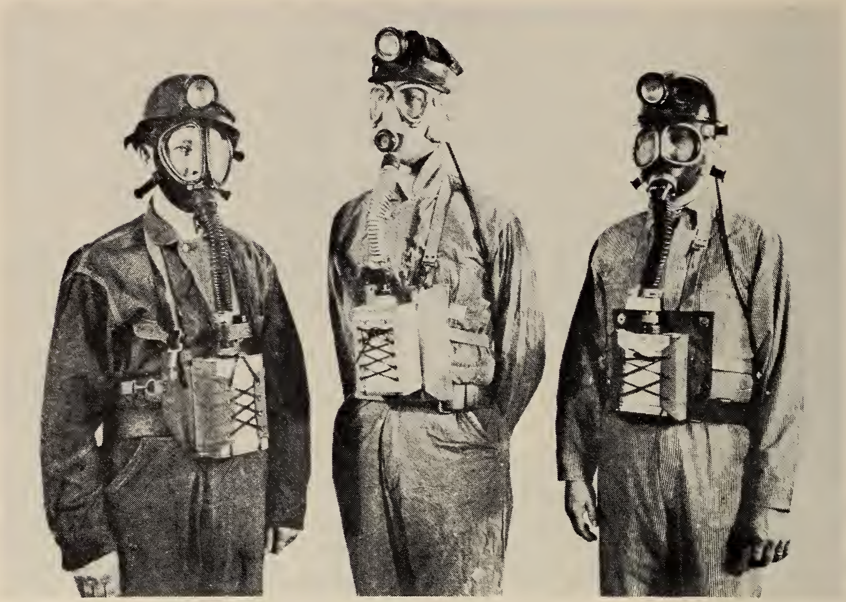

FIGURE 7.—Typical Universal Gas Masks.

of this moisture, the inner surface of the eyepieces may be treated with commercial "anti-fog" or "anti-dim" preparations or with a dilute solution of a synthetic detergent or by applying a small amount of soap and then removing it with a dry cloth. These treatments will minimize the formation of droplets of moisture on the eyepieces.[18]

Figure 8 shows a composite cross section of a universal gas-mask canister and indicates the purpose of each type of granular material that makes up the fill. The various gases, vapors, and solid or liquid contaminants in the air drawn to the canister are removed or rendered harmless as follows (fig. 8):

1. The organic vapor absorbent—activated charcoal—absorbs organic vapors such as acetone, benzene, chloroform, formaldehyde, and gasoline. It also absorbs considerable chlorine.
2. The acid-gas absorbent—alkaline hydroxides with a suitable supporting medium—reacts with acid gases such as chlorine, formic acid, hydrogen chloride, hydrogen cyanide, hydrogen sulfide, phosgene, and sulfur oxide.
3. The ammonia absorbent—silica gel or porous granules impregnated with certain metallic salts—reacts with ammonia gas.
4. The drying agent—anhydrous calcium chloride or some of the ammonia absorbents—removes water vapor from the air before it enters the hopcalite layer.
5. The carbon monoxide catalyst—hopcalite—promotes conversion of carbon monoxide (CO) to carbon dioxide (CO_2). It also reacts with some of the acid gases. It does not function efficiently in the presence of moisture; hence, the canisters contain enough drying agent to protect the hopcalite from water vapor for a 2-hour period.
6. The smoke filters in the regular universal canisters protect against the smokes from ordinary fires and provide limited protection against dust, fumes,

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[18] See footnote 17.

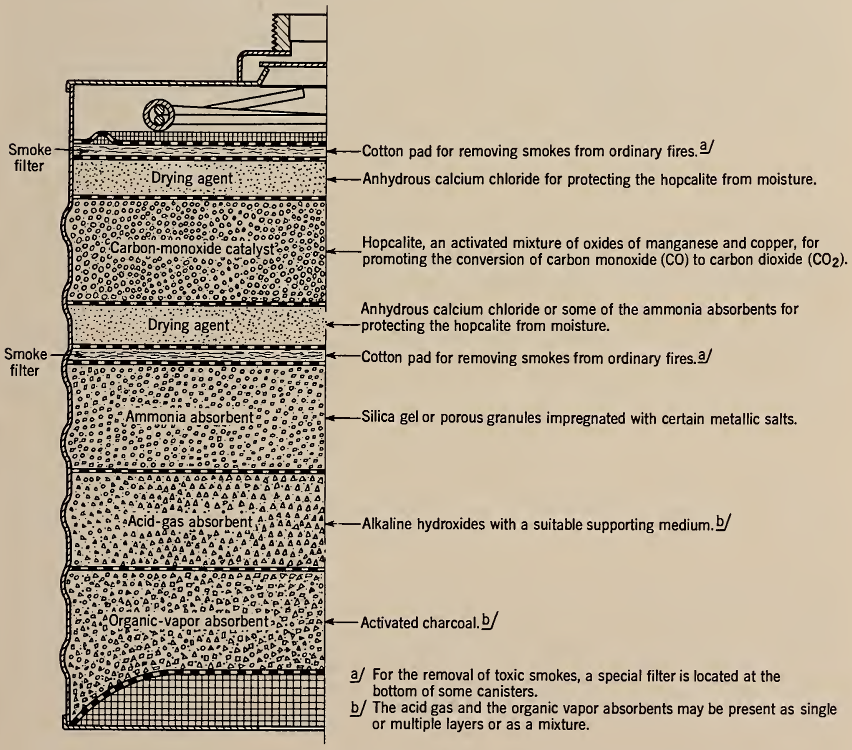
mist, and fogs. Some of the universal canisters have special filters that protect against toxic dusts, fumes, mists, fogs, and smokes.

All universal gas masks are provided with a timer actuated by the wearer's breathing and have a dial that indicates when the mask has been worn for 2 hours—the maximum safe period of use for a universal gas-mask canister.

The gas mask should be examined carefully before wearing to ascertain that it is in proper condition. It should be adjusted carefully to the face and tested as to airtightness. The seal must be removed from the bottom of the canister before the mask is worn.

The gas-mask canister offers some resistance to breathing; practice in wearing masks is desirable to become used to this feature as well as to the details of mask adjustment. No person should wear a gas mask in irrespirable air unless he knows the limitations of the equipment and has had actual practice in its use. The idea that anyone can wear a gas mask without previous training is decidedly dangerous.

Users of self-contained oxygen breathing apparatus should be trained thoroughly in the wearing, construction, and testing of the apparatus and should be proved physically fit, by a doctor's examination, to perform strenuous work with the apparatus. The apparatus should be carefully tested as to airtightness and proper functioning before use in irrespirable atmospheres.


Smoke filter
Cotton pad for removing smokes from ordinary fires.a/
Drying agent
Anhydrous calcium chloride for protecting the hopcalite from moisture.
Carbon-monoxide catalyst
Hopcalite, an activated mixture of oxides of manganese and copper, for promoting the conversion of carbon monoxide (CO) to carbon dioxide (CO_2).
Drying agent
Anhydrous calcium chloride or some of the ammonia absorbents for protecting the hopcalite from moisture.
Smoke filter
Cotton pad for removing smokes from ordinary fires.a/
Ammonia absorbent
Silica gel or porous granules impregnated with certain metallic salts.
Acid-gas absorbent
Alkaline hydroxides with a suitable supporting medium.b/
Organic-vapor absorbent
Activated charcoal.b/

a/ For the removal of toxic smokes, a special filter is located at the bottom of some canisters.

b/ The acid gas and the organic vapor absorbents may be present as single or multiple layers or as a mixture.

FIGURE 8.—Composite Cross Section of Various Gas-Mask Canisters.

The Bureau of Mines recommends that, for trips of any considerable distance in bad air, at least 5 and preferably 6 men wearing apparatus compose the oxygen-breathing-apparatus crew and that there be a second crew of 5 or 6 men with oxygen breathing apparatus ready for use at the fresh-air base. Even under favorable conditions of travel and with such a reserve crew, the Bureau of Mines does not recommend travel by a 5-man crew of over 1,000 feet from fresh air unless there is reasonable chance of saving life.

Oxygen breathing apparatus has the advantage of complete protection of the wearer against irrespirable gases. It cannot be used to advantage in a confined place, and its weight and bulk handicap the wearer in any attempt to do arduous work.

The construction, care, and use of oxygen breathing apparatus and accessories are fully covered in a Bureau of Mines handbook entitled "Self-Contained Mine Rescue Oxygen Breathing Apparatus."

Other types of self-contained breathing apparatus used in combatting mine fires are the Oxygen-Mask, Scott Air-Pak, and Chemox apparatus.

SELF-CONTAINED BREATHING APPARATUS

Self-contained oxygen breathing apparatus gives complete respiratory protection to the wearer, regardless of the outside atmosphere. It is entirely self-contained. However, some toxic gases, such as cyanide, are absorbed through the skin; although the oxygen breathing apparatus protects against respiratory difficulties, it does not protect against skin absorption. In the types of oxygen breathing apparatus generally used in mines compressed oxygen stored in a steel cylinder is furnished through a reducing valve and air reservoir or breathing bag to the apparatus wearer in the quantity needed by the wearer. The exhaled air passes through a regenerator containing a chemical (soda lime, caustic soda, or caustic potash) that removes the carbon dioxide from the air; the air then consists only of nitrogen and oxygen. Additional oxygen is added to the circuit automatically from the storage cylinder to replace that consumed by the body.

Oxygen breathing apparatus is made in 2-hour, 1-hour, ¾-hour, and ½-hour types; the 2-hour types approved by the Bureau of Mines furnish enough oxygen for the wearer to perform 2 hours of strenuous work but weighs nearly 40 pounds; the 1-hour types are also approved and weigh about half as much (fig. 9).

SUPPLIED-AIR RESPIRATORS

The hose mask, used in surface-plant emergencies, may be of limited value in fighting mine fires for a distance up to 150 feet in advance of fresh air. In one type a rubber facepiece is connected with two flexible breathing tubes passing over the shoulders and thence to a nonkinking, noncollapsible hose. A hand-operated blower forces the air through 150 feet of 1-inch hose to the outer air through a rubber flutter valve in the mask facepiece. The construction of the device permits breathing without undue resistance, even though the blower is not operated. The hose mask has the advantage over the gas mask that the wearer has fresh air to breathe, irrespective of the immediate atmosphere around him, provided the outer end of the hose or the blower is in fresh air. It has the disadvantage that a hose has to be dragged by the wearer;

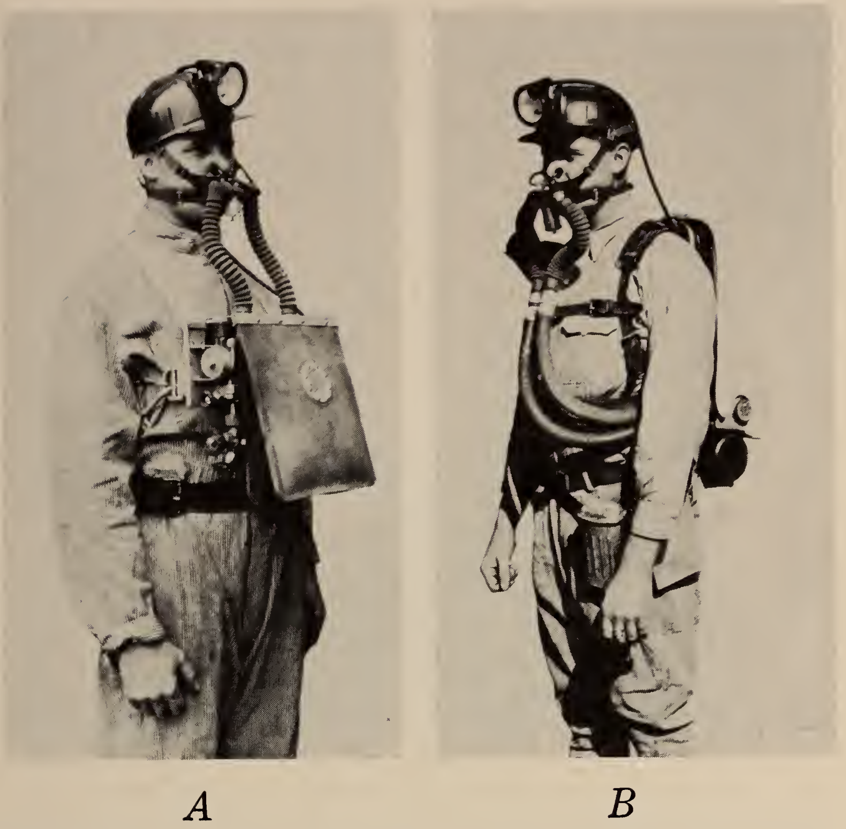


Figure 9.—*A*, Mines Safety Appliances Co. 1-Hour (Front Type) Self-Contained Breathing Apparatus; *B*, McCaa 2-Hour Self-Contained Breathing Apparatus.

this may be only a slight handicap on the level but a considerable one in raises or on ladders. A fall of rock on the hose might prevent the wearer from getting back to fresh air. The hose mask is light and reasonably comfortable to wear.

Type C supplied-air respirators (air-line respirators) with full facepieces are designed to be connected by means of a small-diameter hose to a compressed-air line through a proper pressure reducer. If the air supply fails, the wearer cannot obtain respirable air with this device, as contrasted with the hose mask.

SELF-RESCUERS

The gas masks and oxygen breathing apparatus just described are used to protect men in fire-fighting operations. To assist men trapped by gases from fires and endeavoring to escape carbon monoxide, the self-rescue respirator has been devised.

The self-rescuer is a small gas mask designed to provide respiratory protection against carbon monoxide in otherwise respirable air. Being small, it may readily be carried by the miner while underground and thus be available immediately for protection against carbon monoxide. Self-rescuers approved by the Bureau of Mines have met the requirement that they shall protect a man for at least 30 minutes in an atmosphere containing 1 percent of carbon monoxide. Tests of mine air during mine fires have shown that such air usually contains enough oxygen to support life, that the carbon monoxide in the air from a fire usually kills the miner, and that if he had been protected against this gas he might have escaped.

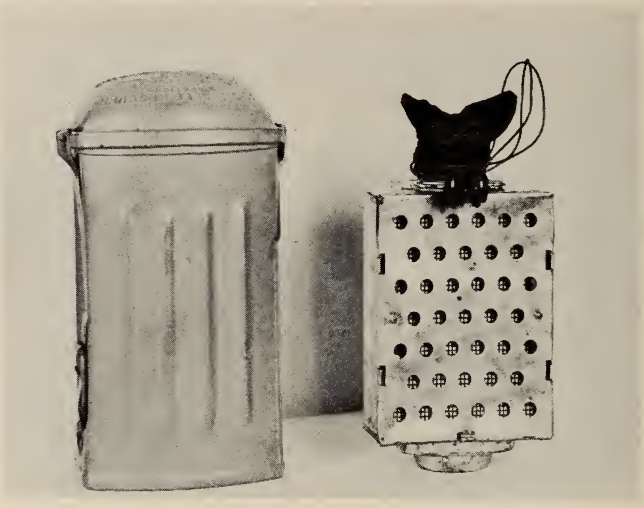


Figure 10.—Self-Rescuer With Hinged-Lid Container.

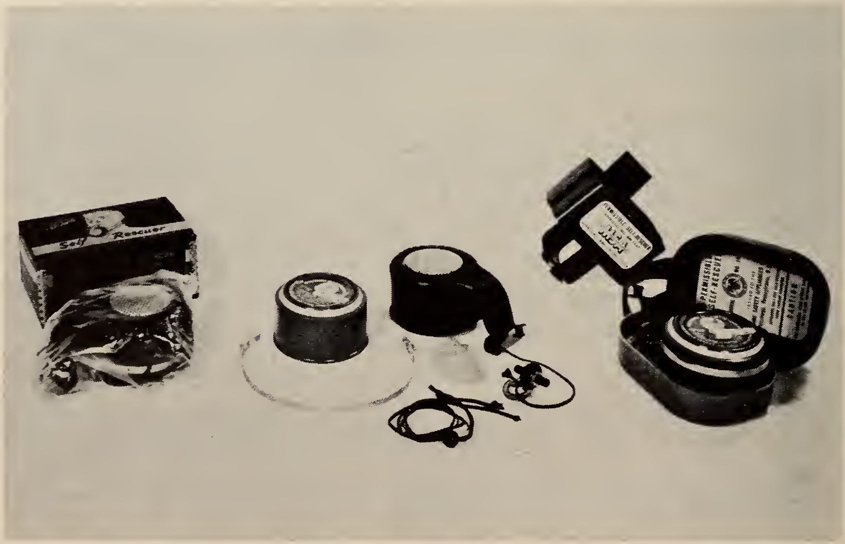


Figure 11.—Self-Rescuer in Plastic Bag.

The two approved self-rescuers (figs. 10 and 11) differ primarily in the seal and storage case; one is hermetically sealed in a metal case with a hinged lid, and the other contains a hermetically sealed replaceable cartridge and is stored in a plastic bag to protect it from dust.

After the seals are broken, the wearer of the self-rescuer breathes by mouth through the canister and adjusts the attached pinch clamps to the nose to prevent breathing any of the outside air. Inhaled air enters the canister and passes successively through: (1) Absorbent cotton to remove the smoke; (2) fused calcium chloride to remove moisture; (3) hopcalite to oxidize the carbon monoxide; (4) another cotton filter; and (5) finally a check valve to a passageway connected to the rubber mouthpiece. Exhaled air passes directly from the passageway to the outside through another check valve. As in the universal gas mask, the hopcalite acts as a catalyst, causing the carbon monoxide and oxygen to unite and form relatively harmless carbon dioxide.

This device, like the gas mask and the oxygen breathing apparatus, is dangerous to use unless the wearer has had previous instruction relative to its limitations and at least a limited amount of practice in wearing it.

EMERGENCY SIGNALS

Common practices to warn underground workers to quit the mine because of a fire or other emergency have been flashes on the signal and light lines, filling air lines with water, rapping on pipes, telephone calls, and introducing odoriferous liquids (stench) into the compressed-air lines. To assure effective warning of men by flashes of the electric lights or by telephones requires an ample distribution of light circuits and telephones to all parts of the mine and near the working places. Very few mines are so equipped.

Stenches used as warnings should be contrastingly different from other odors encountered in normal mine operation. The odor may be offensive or pleasant, but it must be readily detected; the stench must be such that no definitely harmful effects will result if men are trapped and cannot escape. Ethyl mercaptan (unpleasant odor), amyl acetate (pleasant odor), and other chemicals are used as warning agents.

Ethyl mercaptan[19] has the very disagreeable odor of rotting cabbage. Less than 0.01 percent by volume of ethyl mercaptan vapor in air will give a strong odor. It is easily obtainable, relatively cheap, and nontoxic, even in heavy concentrations. About ¼ ounce (8 cc.) is required for each 1,000 cubic feet of free air entering the mine. For the average metal mine about 1 pint is required. Amyl acetate has the same characteristics, except it has the pleasant odor of banana oil. Ethyl mercaptan is generally used.

Twelve stench warning tests were made in the Lake Superior copper and iron mines and are described in Bureau of Mines Report of Investigations 3850.[20]

For the best results stench should be released in the compressed-air lines and the ventilating current simultaneously.

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[19] Harrington, D., and East, J. H., Jr., Stenches for Emergency Warnings in Metal Mines: Bureau of Mines Inf. Circ. 7246, 1943, 7 pp.

[20] Cash, F. E., and Johnson, E. W., Stench Warning Tests, Lake Superior District Mines: Bureau of Mines Rept. of Investigations 3850, 1945, 23 pp.

One mining company, which used stench as a general emergency warning, uses a dye (uranin) for emergency warning to shaft-sinking crews. Because of the small volume of the shaft opening, the ethyl mercaptan was deemed too severe. When mixed with water, the dye gives a brilliant green solution, which is sprayed to the bottom of the shaft to give warning of danger to the shaft-sinking crew.

An ethyl mercaptan vapor-air explosion occurred at the Cerro de Pasco Corp. mine, Morococha, Peru, during a stench warning test.[21] Considerable damage resulted to the compressed-air lines and other surface equipment in the immediate vicinity of the explosion area.

The Cerro de Pasco Corp. requested the Bureau of Mines to review the evidence supplied in connection with the explosion and to offer suggestions as to the cause and to recommend means of preventing future explosions.

Because of its strong penetrating and disagreeable odor, ethyl mercaptan has been used for years as a warning agent in a great many parts of the world. Although it is a flammable material, this explosion seems to be the only one of its kind on record involving ethyl mercaptan.

After a review of the supplied data and various tests with ethyl mercaptan-Freon mixtures, the Bureau of Mines made the following recommendations on the explosion at the Morococha mine:

> If ethyl mercaptan is introduced into the compressed-air lines without the addition of suitable and adequate flame-quenching agents—
>
> 1. The cylinders in which the ethyl mercaptan is used and all other equipment, including screens and breaker mechanism which may contact the liquid ethyl mercaptan, should be constructed of stainless steel.
> 2. The cylinders should be located at the greatest possible distance from the compressors so that the compressor air will have time to cool, and possible hot, solid carbon or other particles from the compressors can be deposited and cooled before entering the cylinders containing ethyl mercaptan.
> 3. A method should be developed whereby the ethyl mercaptan can be fed into the compressed-air stream at a constant and sufficiently slow rate to maintain the concentrations of the mercaptan essentially below the lower flammable limit at all times.

The following method was recommended for eliminating such explosions:

> 1. Warning mixtures should be used that contain 5 parts of Freon–12 to 1 of ethyl mercaptan or 5.3 parts of Freon–22 to 1 part of ethyl mercaptan by weight. Such mixtures when mixed with air in any proportions are entirely nonflammable at ordinary temperatures (70° F.) and 1 atmosphere pressure.
> 2. If the compressed-air temperature is approximately 200° F. and the pressure is 90 to 100 pounds per square inch gage (p. s. i. g.), the above proportions of Freon should be increased by 10 percent.
> 3. Tests made by the Bureau of Mines with experimental mixtures of the type given above have shown that the liquid Freons and ethyl mercaptan are miscible in all proportions; therefore, it is only necessary to prepare the mixtures in metal containers strong enough to withstand pressures of 70 p. s. i. g. when Freon–12 is used or 123 p. s. i. g. when Freon–22 is used at temperatures not exceeding 70° F. At higher temperatures the pressures in the containers will be correspondingly greater. The mixture should be discharged into the compressed air in the liquid phase by having a discharge tube inside the container extend from the discharge valve to the bottom of the container or, if a discharge tube is not provided, by turning the container upside down and discharging the liquid from the bottom.

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[21] Jones, G. W., Zabetakis, M. G., and Scott, G. S., Elimination of Ethyl Mercaptan Vapor-Air Explosions in Stench Warning Systems: Bureau of Mines Rept. of Investigations 5090, 1954, pp. 4, 7.

The cost of blending ethyl mercaptan with Freon is not excessive. Freon–12 (CCl_2F_2) costs about 50 cents and Freon–22 ($CHClF_2$) about $1.50 a pound in Pittsburgh, Pa.

ESCAPEWAYS

A second or emergency escapeway should be accessible to men working underground; exceptions are frequently made to State requirements on this point in small operations of a limited depth, but the procedure should be mandatory. Main avenues of escape, such as shafts or inclines, should be made fireproof, but where fireproofing is not practicable water sprays should be installed at various places to protect the escapeway. All escapeways should be plainly marked with signs that are kept legible, and these escapeways should be inspected regularly to make sure that they can be traveled easily and safely.

Openings through which men normally travel should be on intake air for protection of men from smoke, heat, and other harmful products of a fire underground. Emergency escape openings are often those used for upcast or exhaust air from the mine, and men attempting to use them during a fire might be endangered by smoke and gases. Whether to reverse the direction of airflow during a mine fire, where it is possible to do so, is a serious decision. It should be made only by the highest officials after consideration of all the factors, which are seldom the same in any two mines; hence, no general rule is possible.

REFUGE CHAMBERS AND BARRICADING

One means by which men have saved their lives when trapped by fire is related in the following incident. During the fire in the North Mount Lyell copper mine at Queenstown, Tasmania, Australia, in October 1912, 50 lives were saved by a man who blew compressed air from a hose against the face of the drift instead of against the smoke and made the men keep as close to the walls as possible. On striking the face, the compressed air spread out and prevented the smoke from reaching that point or so largely diluted it that the air was breathable. Since the air supply might fail during a fire and better protection of entrapped men would be advisable, refuge chambers have been provided in a number of mines in sections where men may be cut off from escape by fire or smoke and gases coming from a fire (fig. 12).

Safety chambers used for protection against gas hazards from fire or blasting in the United Verde copper mine in Arizona have been constructed in the dead ends of drifts.[22] A standard-type mine door is installed as far from the face as conditions will permit. The chamber is supplied with electric lights, water, and compressed-air lines. Valves controlling both air and water are inside the chamber; when the compresed air is released, pressure is built up within the chamber so that gases are excluded. During a fire little dependence can be placed on compressed-air lines that may pass through the fire zone, where they may be burned out or broken. Piping should be arranged to flow to the safety chamber from two different sections of the mine if possible. Where the depth from the surface or distance from another

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[22] Glaeser, O. A., Protective Measures Against Gas Hazards at United Verde Mine: AIME Tech. Pub. 276, 1930, 10 pp.

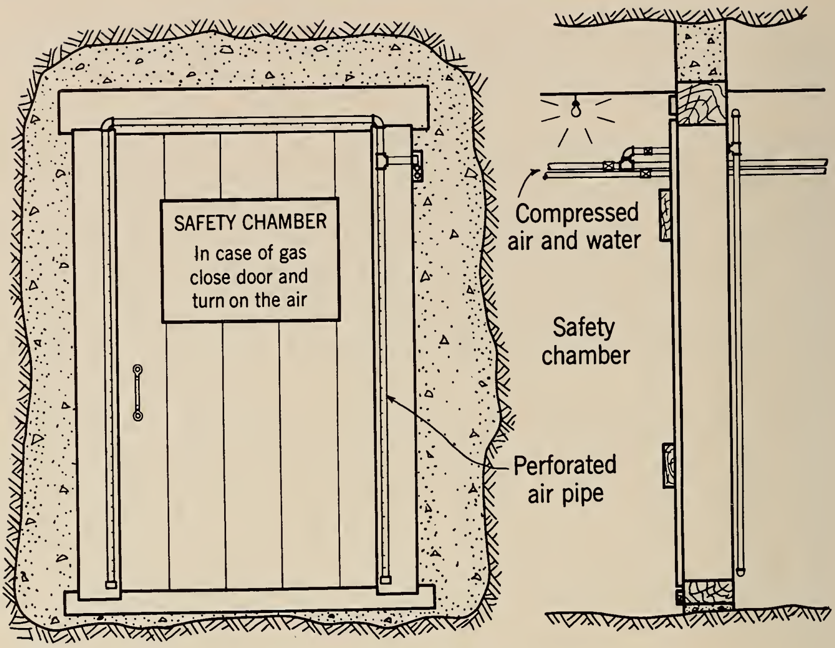

FIGURE 12.—Safety-Chamber Door.

level is not too great, boreholes could be drilled through which pipelines could be run.

A refuge chamber was constructed in the crosscut that connected the 5,700 level (incline depth) of the Argonaut and Kennedy gold mines at Jackson, Calif. This chamber was made by enclosing 75 feet of crosscut between 2 concrete bulkheads with close-fitting iron doors. Air, water, and telephone lines entered the chamber from both mines, the two systems being separate and independent of each other. Fire extinguishers and hose were also provided.

The Frood nickel-copper mine of the International Nickel Co. of Canada, near Sudbury, Ontario, has taken thorough precautions for protecting men during a fire in any part of the mine. In his paper on ventilation of the Frood mine, published in the Canadian Mining and Metallurgical Bulletin for April 1932, R. D. Parker describes the refuge stations as follows:

> On all producing levels and in fresh air ways, refuge stations, of sufficient size (they average 6,500 cubic feet) and number to accommodate comfortably all employees in that area, have been established. These stations are constructed in dead ends or specially driven headings and in virgin ground. Concrete bulkheads with standard-size steel man doors are built as far from the face as is practicable. Doors close against their frames and are so constructed that they may be readily clayed tight. Each door is equipped with a pressure-release opening with a wooden plug attached so that it may be closed readily and completely. Special latches hold the doors tightly closed and operate from either side of the opening. Back support is of the standard steel drift type. Wooden benches 8 inches high and 3 feet wide are installed on both sides of the station for its entire length. Floors are of concrete so that they may be cleaned and drained readily.

> All stations are equipped with electric lights, telephone, compressed-air and water lines, drinking fountain, water-storage can, and wet clay (two cans).
>
> Each working area at the present time has two refuge stations as described. One of these, however, in every area is used as a supply station. Refuge stations used as supply stations are equipped with two sets of telephones. One of these is a part of the regular mine telephone system feeding back to and up through shaft 3. The other telephone belongs to the regular refuge-station installation—a unit within itself and carried into the mine through the ventilation shaft. Within each refuge station are posted specific regulations to cover procedure in case of using the stations.
>
> To familiarize employees with the location of the refuge stations in their particular area, it has been made compulsory for them to eat their lunches within them. On the occasion of any meetings underground, they are also held in these stations.
>
> All operating levels are under the direct supervision of a foreman on each shift. The prearranged procedures are posted in all refuge supply stations, and the level foremen, after having learned the fire area, can direct the movements of their men and the setting of fire and ventilation doors in a minimum of time and with the least confusion.

The Bureau of Mines has consistently called attention to the utility of barricades erected by men who are prevented from escape in mines during a fire and has issued several publications giving instructions on the procedure.[23]

One instance where men were saved by a barricade is afforded by a fire at the Cardinal mine near Nederland, Colo., in December 1925. The mine had been worked for many years and produced lead ore carrying gold, silver, and copper. A tunnel 3,300 feet long was heavily timbered at the portal. Fire, which destroyed the surface buildings, spread to these timbers, imprisoning 20 men and 2 horses. The men retreated to a drift branching off the face of the tunnel and put up a bulkhead of timber, boards, mud, and clothes. Several men were more or less overcome with smoke while erecting the barricade. One horse was taken back of the barricade with the men; the other was lost in the smoke. The barricaded section had open stopes and drifts above it, but there were no connections to the tunnel through which smoke or gases could enter. Rescuers reached the barricade about 12 hours later, entering the mine through an air shaft. One man wore a 1-hour oxygen breathing apparatus, but three others are said to have entered without respiratory protection. The four reached the barricade and tapped on the air pipe to notify the men behind the barricade of their presence. The rescuers then pulled off two or three of the boards of the barricade and smoke poured in through the opening. The three rescuers without apparatus collapsed and two were pulled inside the barricade by those behind; one was unconscious for 2 hours yet recovered, but the other died. Later, two men from the imprisoned group dashed outside with the third unprotected rescuer and the one with apparatus; the last probably saved the lives of two of his companions, but the other was found dead. Finally the fire was sealed off, the smoke cleared from the tunnel, and the barricaded miners walked out or were hauled out in mine cars by the horse they had taken in with them. In this instance, little time was lost in deciding upon the erection of a barricade, and it was built quickly. There was enough air in the bulkheaded workings to last the men 2 or 3 days.

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[23] Harrington, D., and Fene, W. J., Barricading as a Life-Saving Measure Following Mine Fires and Explosions (revised December 1946). Bureau of Mines Miners' Circ. 42, 1948, 64 pp.

When barricading is done, dependence is placed upon early success of efforts to control the fire; if the fire has to be sealed and men are barricaded within these sealed regions, there is little hope for their survival unless boreholes or compressed-air lines are run into the place barricaded. If the confinement is prolonged, food and water may be required.

Some suggestions regarding barricades follow:

1. Miners behind a barricade should not group closely if the oxygen content of the air is being lowered.
2. Workings back of a bulkhead should not be in broken or filled ground through which gases may penetrate.
3. If carbide lights are used, only one or two should be kept lighted. Spent carbide should be thrown outside the barricade, if possible.
4. A double barricade is advisable.

FIRE DOORS

Fire doors are used to cut off a fire or the fire gases and smoke from the rest of the mine, thus checking the fire or preventing the gases from spreading throughout the mine.

A shaft or adit opening that has combustible buildings or timber or any nonfireproof material near or about it should have metal fire doors that can be closed readily; they should be in a concrete or other incombustible frame. These doors should fit as tightly as possible. Although they are used chiefly to exclude fire and gases from the mine, they also help to check the progress of fires in the mine by cutting off the draft.

Doors should be placed so as to isolate shafts from mine levels. Such doors and their frames should be substantially constructed and should preferably be covered with roofing iron or otherwise fireproofed, although wooden doors may suffice if in untimbered sections far enough from other timber or combustibles to avoid becoming ignited. Fire doors should be built to close flush against the face of the doorframe rather than in a groove within the frame, so that ground movement or swelling of the door or frame will not prevent closing of the door. They should have a latch that can be operated from either side or equivalent device so that they can be kept closed when desired even if the air pressure or direction of ventilation is reversed. Where practicable, doors that are important in cutting off gases from a shaft fire should be kept closed except while hauling through them. Doors that must be closed by personal effort in case of fire cannot always be effective, as they may be impossible of access; some companies have constructed important doors so that they can be closed automatically by compressed air from the surface or at a station. At the Copper Queen mine the automatic doors are held open by a latch, which is kept closed by an air cylinder acting against a counterweight.[24]

> The air cylinders were connected by piping with all doors protecting the shaft and with the compressed-air main on the surface. By opening a valve at any station or at the surface, the pressure in this system and the cylinders is relieved and the weights throw the latches, allowing the doors to close (figs. 13 and 14).

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[24] Sherman, G., Measures for Controlling Fires at Copper Queen Mine: Trans. AIME, vol. 59, 1918, p. 319.

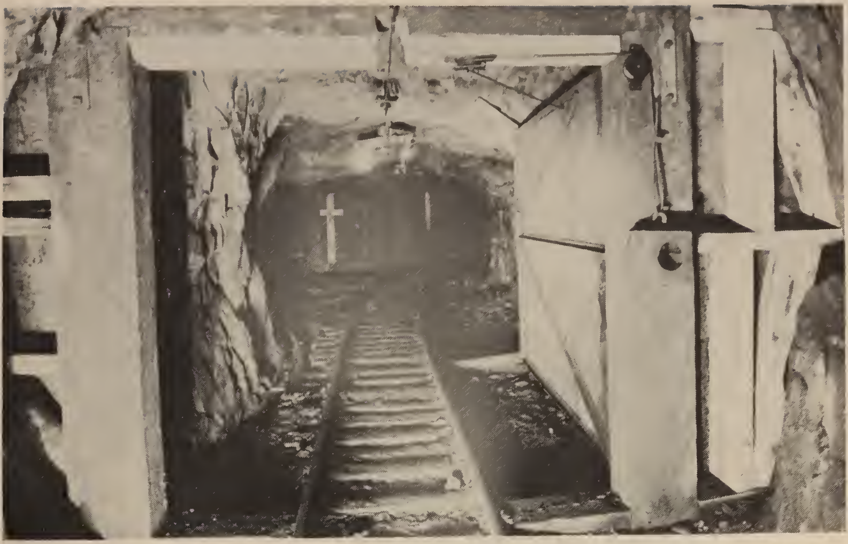

FIGURE 13.—Counterweight Closes Fire Door When Compressed-Air Trip Releases Catch.

Sectionalizing mine workings by fire doors should be seriously considered where there is an underground fire hazard. Ventilation doors will also serve as fire doors in many instances, and the control of ventilation is an important factor that must also be weighed in planning for the control of possible underground fires. Generally, if air currents can be cut off from the section of a mine in which a fire is discovered, the fire can be held in check when direct efforts to extinguish it cannot be employed.

Figure 15 shows a sectionalizing ventilation and fire door.

SEALING FIRES

When a fire gains such headway that it is impossible to fight it directly or if it is in an inaccessible place or in a place in which falling material prevents actual contact, the only recourse is either sealing or flooding. Seals of clay, sand, boards, canvas, brick, tile, concrete block, lath and wood fiber, or concrete are erected to confine the fire fumes within a restricted area with minimum leakage of air (fig. 16). Where the seals are made tight and maintained tight and the surrounding strata are not broken, the oxygen content of the air within the sealed area is soon depleted below the percentage necessary to support combustion and the fire will go out.

Experience by the Bureau of Mines in sealing fires in coal mines shows that combustion has continued in some instances with 4 to 5 percent oxygen in the air behind the seals. This indicates that, if complete extinguishment of the fire is sought, sealing should be continued long enough to allow the region under seal to cool, until carbon monoxide (CO), which is an indicator of combustion, has disappeared, and the oxygen percentage has dropped below 4 percent. Even if

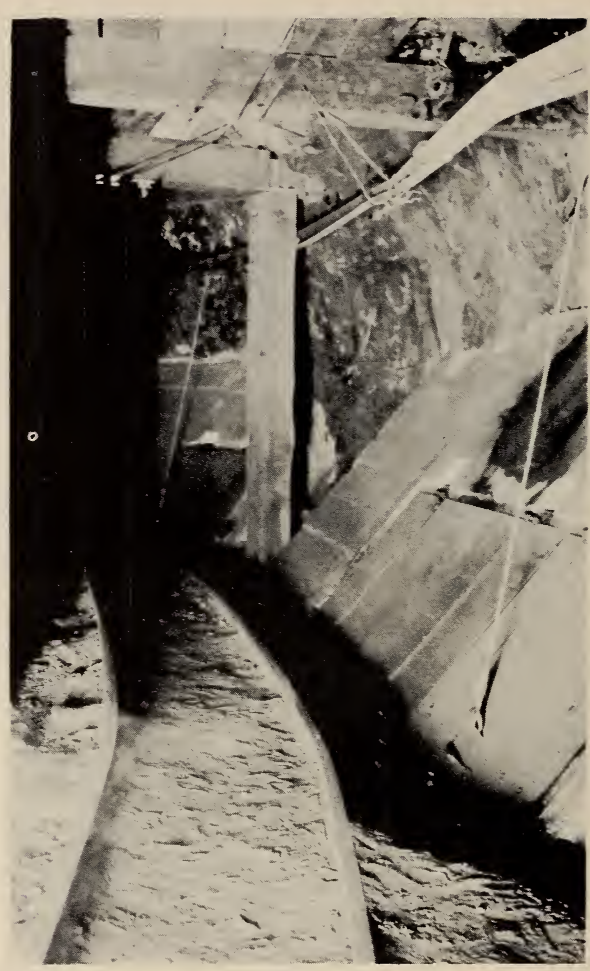

FIGURE 14.—Metal Fire Door on Concrete Frame at Top of Raise.

sealing does not extinguish a fire, it will impede and perhaps entirely stop its spread and will permit the assembling of enough fire-fighting equipment to combat it adequately.[25]

The cement gun may be useful in cementing broken ground to prevent escape of fumes, in making bulkheads of timber, rock, and boards airtight, and even in constructing cement or concrete bulkheads. Cement grout may also be forced into broken ground through pipes to form an effective, firm, tight seal.

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[25] Forbes, J. J., and Grove, G. W., Procedure in Sealing and Unsealing Mine Fires and in Recovery Operations Following Mine Explosions (revised May 1948): Bureau of Mines Miners' Circ. 36, 1948, pp. 31–72.

Scott, G. S., Anthracite Mine Fires: Their Behavior and Control: Bureau of Mines Bull. 455, 1944, pp. 74–75.

Ash, S. H., Extinguishing a Fire at the Argonaut Mine: Min. Cong. Jour., vol. 25, May 1938, pp. 20–25, 53.

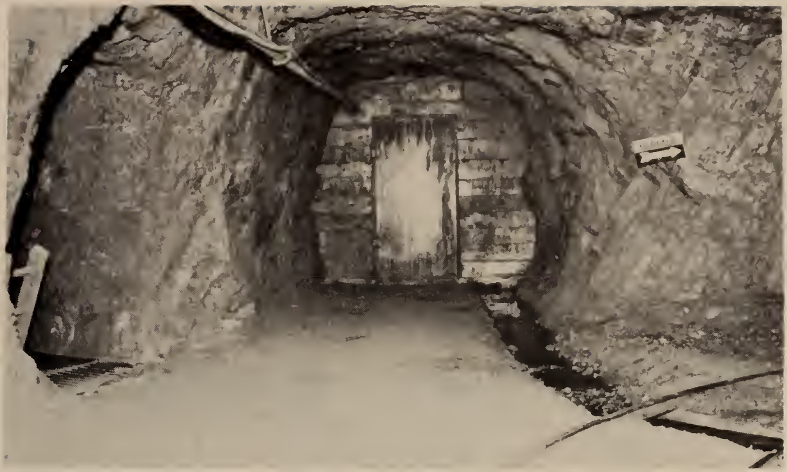

FIGURE 15.—Steel Fire and Ventilation Door in Concrete Frame. (Note the top of the emergency exit raise at left and the surface arrow at right.)

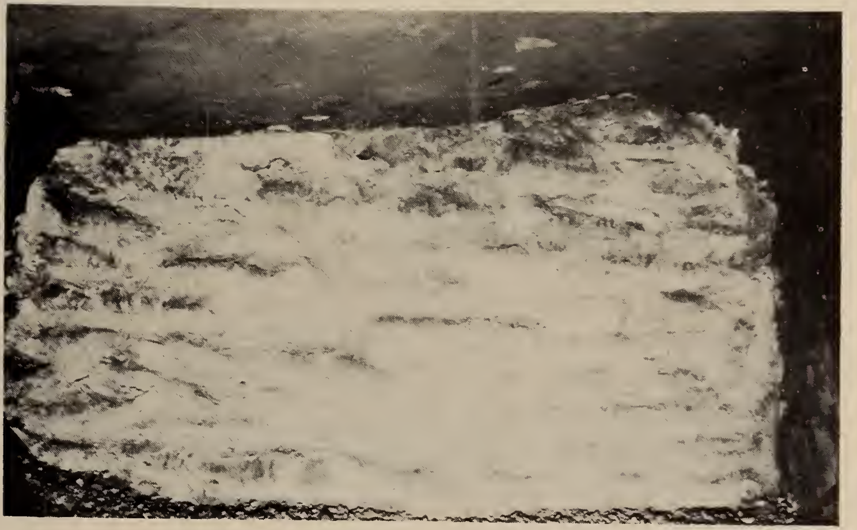

FIGURE 16.—Rock Bulkhead Laid With Mixed Cement and Clay.

When the fire is in moving or in heavy ground, rigid bulkheads of cement and rock are ineffectual, and bulkheads of timber laid skin to skin can be held tight much more readily than those of cement and rock; with cement and rock bulkheads, construction of the upper part and possibly the sides with clay is frequently advisable to allow for movement without cracking the bulkhead.

It is often advantageous to erect temporary stoppings of canvas, boards, or other material before erecting or completing a tight permanent seal. A recent development to speed up the erection of a temporary stopping is the inflatable brattice, which consists of elongated bags of Neoprene-coated cotton-duck covering and plastic bladder. When inflated with air, they fill a mine drift opening and fit fairly snug against bottom, sides, and back. They can be safely inflated inside timbered drifts to block off smoke from a fire and permit permanent seals to be erected under favorable conditions. The inflatable stopping sections may be erected horizontally or vertically (figs. 17 and 18).

Permanent seals should be well hitched into the rock, and all cracks should be sealed. A pipe or pipes fitted with suitable valves should be placed in one or more of the fire seals. Such pipes permit air behind the seals to be examined and sampled and water-gage readings

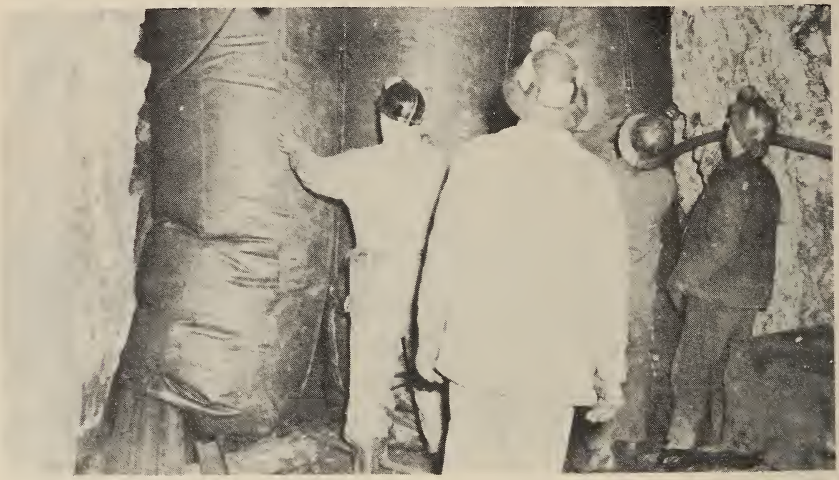

FIGURE 17.—Temporary Fire Seal; Vertical Erection.

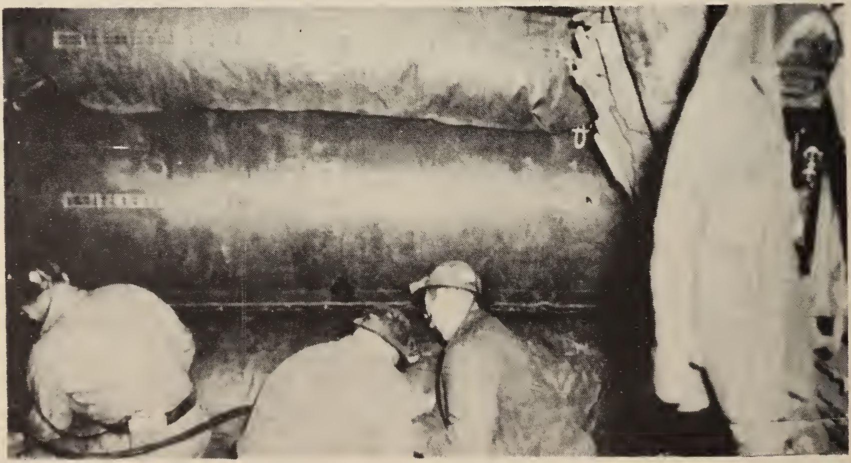

FIGURE 18.—Temporay Fire Seal; Horizontal Erection.

to be taken. Pipes and valves may also be desirable in some of the seals for flooding or draining the fire area. In metal mines seals should be placed as close to the fire as possible.

FLOODING FIRES

Where a fire has gained too much headway to fight it directly and where sealing and the use of inert gas may not be effective, flooding may be the last resort. Flooding the entire mine or a large part of it is very costly both from the standpoint of pumping and because of the likelihood of having to reopen caved drifts and stopes.

Unless it is possible to cover the fire area completely with water, the fire may not be extinguished, although the part of it reached by water will be cooled considerably. Arizona experience[26] demonstrated that water, steam, and carbon dioxide were equally ineffective unless the fire district could be sealed and the extinguishing agent brought into complete contact with the fire.

A fire was extinguished successfully by flooding at the Utah Apex mine, Bingham Canyon, Utah, in March 1917.[27] This fire was caused by spontaneous combustion in a square-set stope off the 1,300 level. The ore consists of galena, pyrite, and sphalerite. Isolation of the fire zone by bulkheads meant a loss of 100,000 tons of reserve ore, with the probability of the fire breaking out into new work. Between 600 and 700 g. p. m. of water was available, and it was estimated that 15,000,000 gallons would be required to fill the mine to about the fire level. Four to five days' flooding sufficed for the water to reach the fire, after which flooding was continued several days. Bailing tanks were used in unwatering the mine, and good progress was made until the landing chairs were encountered at the 1,300-foot level. Much difficulty was encountered in getting these chairs out of the way because of carbon dioxide and nitrogen gas hanging above the water. After the mine was unwatered, about 1 foot of mud was found on the 1,500-foot level. In the region of the ore bodies the drifts and raises were virtually blocked with fine ore. The slices in the stopes adjoining the square-set stope which had been on fire had virtually filled with ore, but timbering was in good condition. In mining after the fire the practice of sealing all openings to stopes as soon as they were finished was adopted. Approximately $40,000 was expended during the 3-month period of the fire and unwatering.

Similarly, in 1907 it was expedient to flood a serious fire in the Homestake mine, Lead, S. Dak., caused by fuse or explosives. Approximately 40 days was required to fill the mine above the fire level, and over 643 million gallons of water was pumped out of the mine in a 4-month period. There was little damage to the mine from flooding, and the fire was extinguished.

Instances are reported of sulfides or carbonaceous shale refiring spontaneously after the water had been removed; such instances are common in some subbituminous coals.

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[26] Tolly, R. E., Mine-Fire Methods Employed by the United Verde Copper Co.: Trans. AIME, vol. 55, 1916, pp. 186–202.

[27] Rood, V. S., and Norden, J. A., Engineering Problems Encountered During Recent Mine Fire at Utah Apex Mine, Bingham Canyon, Utah: Trans. AIME, vol. 61, 1919, pp. 204–215.

USE OF CARBON DIOXIDE

For a number of years carbon dioxide has been used sporadically and successfully in coal and metal mines to cool and extinguish mine fires. It has been introduced in the form of a liquid, as a solid (dry ice), and as a gas. Carbon dioxide is resorted to when fires cannot be extinguished by direct methods or effectively sealed.

Coal-mine fires in Illinois, Pennsylvania, and Washington were successfully extinguished by sealing off the openings to the area and using carbon dioxide inside the seals. In Illinois gas was used, and in Pennsylvania and Washington carbon dioxide was employed in the form of dry ice. In each instance it had been found impracticable to seal the fire area tightly. The seals that were constructed helped to confine the gases but did not exclude oxygen entirely.

The extinguishment of a shaft fire in a Lake Superior iron-ore mine after the usual methods had failed is described by Felegy and Fellman.[28] The procedure in connection with this fire justifies the detailed description that follows:

> Smoke from a fire in the downcast shaft was detected by a shaftman underground at 4:30 a. m. April 19, 1951. He immediately notified the hoist engineer and underground workers. No one was killed, injured, or trapped in the mine by the fire. A crew of 37 men underground at this time left the mine through another shaft 1,450 feet west of the burning shaft.
>
> Several possible causes of the fire were considered, including: (1) Smoking; (2) electricity; (3) spontaneous combustion in the fill around the collar of the shaft; (4) sparks from a passing locomotive; (5) friction; or (6) sabotage. The final consensus of company officials and Bureau engineers is that the fire originated from a cigarette thrown or dropped into the shaft or sucked into the shaft by the fan duct.
>
> The fire was confined to the downcast shaft, which was lined with concrete lath. Wood blocking behind the lath in the hanging wall was consumed from the collar to the 15th level, an inclined distance of 805 feet, and from the 21st level to the 25th level pockets, an inclined distance of about 500 feet. The entire mine was shut down for 38 days until May 26, and only part production was obtained for approximately 2 months.
>
> The mine is served by 2 inclined shafts each about 2,462 feet deep on the incline. Air is drawn down the supply shaft by an axial-flow fan located in the mine, handling about 50,000 c. f. m. at about 1.2 inches water gage. This air is forced along the upper level, where it downcasts through about nine raises to the lower level to return out to the main hoisting shaft. A collar fan on the supply shaft furnishes heat for winter ventilation.
>
> Attempts at fighting the fire with fire extinguishers and fire hose appeared to be successful at the start, but later the fire broke out with renewed energy. Smoke was pouring from a hole 30 feet below the concrete collar on the east side of the hanging wall. The appearance and direction of the smoke gave the impression that the fire was located in the porous fill around the collar, and attempts were made to direct water up into the fill. At the same time holes were drilled through the concrete floor at the shaft collar to get the water on the fire from above. The steel-supported shaft was lined with concrete lath, and wooden blocking supported the rock. Holes were made in the lath and water streams directed behind the lath. This was unsuccessful because only a small area could be wetted; the water soon dropped through the lath and fell to the footwall, where it was useless in combatting the fire.
>
> It was later determined that the fire was below the collar rather than in the porous fill and that the smoke was coming up from behind the lath, the result of a motive column formed by the downcast cool air in the shaft and the rising heated air behind the lath.
>
> An attempt was made to reduce the quantity of air reaching the fire by opening doors and stopping the underground fan. This resulted in the shaft

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[28] Felegy, E. W., and Fellman, C. M., Fires and Fire-Prevention Practices in Lake Superior District Iron Mines: Proc. Lake Superior Mines Safety Council, 1952, pp. 66–70.

immediately becoming upcast. The doors were closed and the fan started again to clear the smoke from the collar so that the fire-fighting crew could work in the shaft.

At about 3 p. m. the same day it was apparent that the fire was out of control and that the shaft had to be sealed. The main fan was shut down and the shaft allowed to become upcast to provide a fresh-air base by natural ventilation from the other shaft.

Since it was imperative to stop the flow of air to the burning shaft as soon as possible, bulkheads were constructed on the 26th, 27th, and 28th levels and at a pentice to the bottom level near the other shaft. The seals were constructed of 2- by 4-inch uprights, 1-inch shiplap, tar paper, wire mesh, and plaster. Most of them were placed on the concrete frames of fire doors which were in solid ground and well hitched into the rock. Initial work on the seals was done under oxygen. Later, when Bureau of Mines personnel arrived, tests showed that the quality of air at the seals did not necessitate respiratory protection. Oxygen apparatus was kept on hand at the seals, however, until work was completed. The seals, including a cover at the collar, were completed by 3 a. m. April 21.

Some difficulty was experienced in obtaining an airtight collar seal. A heater fan duct, which opened into the shaft below the collar, was sealed in the fan room. Vent doors were closed, and cracks in the frames were plastered with wet clay. Both skips were raised into the headframe and the steel doors closed over the shaft opening. Wet clay was packed over all visible cracks and kept moist by spraying with water.

Later it was decided to construct air locks on both the 27th and 28th levels to facilitate access to the shaft stations. They were constructed with doors large enough to permit men wearing breathing apparatus to pass through without difficulty. Three-quarter-inch pipe was installed through both seals of the air lock to permit sampling of the atmosphere without entering the air lock. Bottle samples were taken on the 27th level because the air lock on that level was nearest the sealed shaft.

Frequent and violent changes of pressure beneath the surface seal were evident for a few hours after the seal was completed. On several occasions the pressure changes were sufficient to turn the surface fan at high speed. One particularly violent change created a negative pressure strong enough to bend the metal hasps on the heater-fan doors, allowing the doors to open. Probable cause of these pressure releases was attributed to the fire acting on a large sealed area or falls of ground in the shaft.

Analyses of air samples showed little improvement in conditions after the first week elapsed. Because of possible leakage through numerous surface cracks in the shaft area, plus the possibility of air entering through the porous fill around the collar, it was believed that a new seal at or below bedrock would be more effective in extinguishing the fire.

Work on this seal started the morning of April 28. A 24-inch Naylor vent pipe was lowered into the shaft a few feet below the selected site of the seal. The pipe was mounted on angle-iron runners to fit the track gage. The upper end of the pipe was fitted with a tee reduced to attach two 16-inch-diameter pipes, which connected to two 7,000 c. f. m. fans. Connections at the tee were made with 16-inch Flexhaust tubing to permit some up-and-down movement in the shaft. By operating the two fans in parallel and exhausting through the pipe, fresh air was drawn into the shaft, making it possible to do this work on the seal without apparatus.

A 2-inch pipe, long enough to reach 20 feet below the site of the seal, was equipped with a fog nozzle. It was in operation continually during the construction of the new seal.

The seal was completed at 3 a. m. April 29. There was an increase in smoke during the last few hours of construction.

Air samples were collected in vacuum bottles each day from behind the 27th level seal and from below the collar seal. Carbon monoxide tests were made with the hand-cranked indicator and the colorimetric tester and, when the carbon monoxide concentration reached higher limits, with the Hoolamite detector. In addition, tests for oxygen and carbon dioxide were made with the Fyrite equipment manufactured by the Bacharach Industrial Instrument Co. Results obtained with the Fyrite instruments checked closely with the analyses of bottle samples taken at the same time. The equipment is compact, simple to operate, and gives immediate results. It originally was designed for testing flue gases to determine furnace efficiency.

Analyses of collar air samples, after the new collar seal was completed, showed a definite downward trend in carbon monoxide. However, a rising barometer invariably was followed by an increase in oxygen and air-free carbon monoxide below the collar, indicating leakage into and fire in the sealed area. A falling barometer resulted in a decrease of these gases.

Analyses of bottle samples collected at the 27th level seal showed gradually decreasing oxygen and increasing carbon dioxide, with carbon monoxide usually reported as a possible trace. Except for a few days after the collar seal was opened, tests with the colorimetric tester showed no trace of CO behind the seal. The presence of carbon monoxide at the collar and its absence at the 27th level gave rise to the belief a block had formed in the shaft between the fire area and the 27th level seal.

Because of the disturbing analysis at the collar, company officials and the Bureau engineers decided to add carbon dioxide to the area under seal.

A tank truck carrying 16,000 pounds of liquid carbon dioxide arrived on May 17. The temperature of liquid carbon dioxide at atmospheric pressure is about minus 110° F. Carbon dioxide, first in gaseous form and later as a liquid, was introduced into the shaft through a 2-inch pipe. The tank was emptied the night of May 18. Its injection created a negative pressure on the shaft, tending to draw in fresh air.

A second tank arrived May 20, and the gas was admitted together with steam, with the flow of carbon dioxide being shut off whenever the shaft became negative. The tank was emptied May 22.

Air samples at the collar showed an increase in oxygen, a trace of carbon monoxide, and naturally a high carbon dioxide content. The samples on the 27th level showed increased oxygen and carbon dioxide (air-free), discounting the theory of a shaft block.

Company officials decided to open the shaft to locate the fire, if present, and fight it directly. This was done on the morning of May 23 with a three-man crew wearing oxygen apparatus riding the west cage. A hole in the bottom of the cage permitted men to inspect the shaft as they were lowered slowly. The cage was controlled by a portable signal cord.

By 3 p. m. May 24, 350 feet of shaft was examined. All blocking behind the concrete lath was completely burned out, the hanging wall had caved in some areas, and the unsupported back was 15 feet above the lath at some points. There was little damage to shaft steel.

No active fire or smoke was found, and carbon monoxide did not increase; therefore it was decided to ventilate the shaft because further inspection was too hazardous.

The heater fan was started at 7:20 p. m. May 24 and operated exhausting. Small doors on the 28th level seals were opened after checking the pressure, which changed from a positive of 0.6 inch water gage to a negative pressure of 1.5 inches after the fan started. Pressure on the mine seals varied with the barometer. However, after the carbon dioxide increased considerably over normal air and oxygen decreased, pressures remained positive. By the morning of May 25th the carbon monoxide had completely disappeared at the collar. The fire was out.

The 27th level seals were removed, and the main fan was run in reverse to assist the heater fan. Later, following inspection of the working plates, ventilation was restored to normal.

A gob fire was extinguished with carbon dioxide gas in the Lake Superior district in 1947.

The uses made of carbon dioxide have shown that simply spraying the gas onto a fire of heated broken material in imperfectly sealed workings is not altogether effective. Rapid application of high concentrations of carbon dioxide in the liquid form to the fire area keeps fresh air from reaching the site of the fire by action of the original discharge pressure and by the local pressure developed by the expansion of the gas, which will make a blanket of inert gas surrounding the seat of the fire. The use of dry ice has some advantages: Small cakes of dry ice can easily be taken to a fire area; the inert gas expands as released (1 pound of dry ice forms approximately 9 cubic feet of carbon dioxide gas) and forms an envelope around the fire; and the low temperature of the gas produced cools the area and retards diffusion.

In using carbon dioxide to combat mine fires circulation of the air must be so controlled that the gas can reach the fire and yet not be dissipated. According to McGuire,[29] such control may be obtained with the following equipment: Permissible blower fan, 2 dry-ice containers, and 200 feet of 6-inch duraluminum pipe in 10-foot lengths, with various angle elbows.

With this equipment, the suction pipe and inlet to the fan are connected to one seal, and the discharge end of the pipe is connected to another seal or to the same fire seal, if no other is readily available. The 16-gage sheet-metal tanks containing dry ice are placed in the circuit, usually one on each side of the fan, to keep the fan motor cool. All pipe, fan, and dry-ice-container connections are made airtight to prevent outside air from entering the circuit. The fan is started, and the fire gases from the sealed area flow through the carbon dioxide-generating containers, where the fire gases are cooled and exhausted back into the sealed area. Thus, through a positive mechanical, fire-gas recirculator and the addition of carbon dioxide, nonexplosive and low-oxygen gas mixtures are rapidly generated and cooled to overcome natural adverse conditions, which normally permit air to enter the sealed area and cause the fire to burn.

PLENUM SYSTEM

The Plenum system has been used successfully in opening up and mining fire areas in heavy sulfide ore where the fire has burned out the timber and fired a large mass of broken ore. The system consists of forcing and maintaining air under 2 to 5 pounds pressure in the fire area and cooling the ground enough to permit working there. The spent gases and air find their outlet through fractures into abandoned workings to the surface or through special air raises driven so as not to impede mine working. Evidently, the success of this procedure must depend upon being able to provide an outlet for the hot gases without spreading the fire.

SLIME FILLING

Introducing water or steam through diamond-drill holes into stopes or ore bodies on fire has failed in some instances to control the fire; slime filling in these and other instances has been used successfully.

In 1906 the Anaconda Copper Co.[30] experienced a large fire, probably starting from spontaneous combustion, which finally spread downward through cracked pillars until it became necessary in 1917 to bulkhead off portions of three mines. The sections walled off had been mined by the square-set method. Mill tailings were obtained from a mill and from a mill pond and pumped, as a sludge, into the fire area. Access to the fire area was obtained by opening old drifts and driving new ones to reach the top of old stopes. When close approach to the fire area was impossible, diamond-drill holes were bored. In driving toward the fire the drifts often were pressurized by means of double doors and a Sirocco fan with 12- or 16-inch tubing to hold back the gases. Much of the work was done by men wearing oxygen breathing apparatus. More than 800,000 tons of solids were introduced. On reopening several crosscuts and drifts, the tailings were found to have filled the openings completely; they were well drained and compact enough to pick to a vertical face. This slime filling permitted the recovery of several million tons of ore; where applied, it extinguished the fire in almost every instance, reduced and in places eliminated fire gases, cooled some of the abnormal rock temperatures, improved ventilation, and tended to stop further movement of the ground.

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[29] McGuire, L. H., Extinguishing Mine Fires by Dry Ice or Carbon Dioxide: Pres. before Nat. Safety Cong., Chicago, Ill., October 8–12, 1951, 20 pp.

[30] Rahilly, H. J., Mine Fires and Hydraulic Filling: Trans. AIME, vol. 68, 1923, pp. 61–72.

Slime filling is still being used in the Butte mines for controlling and extinguishing mine fires in broken ground. This method has also been employed at Homestake and at the Empire Zinc Co. mine in Colorado.

FIRE-FIGHTING ORGANIZATION

PLAN OF ACTION

Many fires could have been extinguished in their early stages had a fire-fighting organization and adequate equipment been available. All bosses, surface and underground, as well as clerks, timekeepers, and other employees, should be brought together into an organization to periodically discuss possible fires and to determine what each should do during a fire on the surface or at various places underground. There should be posted in the mine office and kept up to date a list of names and street and telephone addresses of persons to be notified in case of fire, including mine officials, safety men, oxygen mine rescue-apparatus men, State inspectors, doctors, and in some places ambulance drivers. All bosses, cagers, motormen, and samplers should be fully acquainted with the location of valves and electrical switches and should be thoroughly instructed as to the action to take during a fire, first, toward assuring the safety of the men and, second, toward protecting property. Training should be of such nature and scope as to insure intelligent direction and strict discipline in all activities at or around a mine fire, from the moment of discovery until it is brought under control. To insure the familiarity of all employees with the procedure and appliances provided for fire emergencies and with emergency exits, fire drills should be held frequently by selected men or in some instances by all men on each shift. At these drills men need not be removed from the mine but may be assembled in the main exits or in the stations. Forethought and planning for possible emergencies of this kind will disclose weak points in general arrangements and can well be done in connection with training of mine rescue-apparatus crews.

GENERAL FORM OF ORGANIZATION

A capable, efficient organization of men well trained and experienced in the duties they are to perform in a disaster often may save the lives of entombed men and prevent needless risk and possible loss of life among men fighting fires or rescuing trapped miners.

At some mines a working organization has been planned, composed of company officials or cooperating officials of several companies in a district. At many other mines it is assumed that officials will carry on necessary action in emergencies. A planned organization should carry out duties somewhat as follows:[31]

Superintendent: See that all other officials are functioning and provide for assistance where needed. Direct plan of action on reports from experienced assistants. Deal with outside agencies and call for available assistance.

Mine clerk: Remain at telephone at headquarters established by superintendent. Provide information bureau, messrooms, emergency hospital, and sleeping quarters.

Supply clerk: Stay at supply room. Provide tools and equipment.

Master mechanic: Keep attendants at hoists, compressors, and fans. Provide mechanical equipment and assistance on call.

Topman: Check men in and out of mine by written record. Allow no one to enter, except as authorized by officials in charge.

Mine foreman: Organize underground operations in cooperation with superintendent and with State inspector on arrival. Arrange for necessary crews as needed.

Chief engineer: Provide maps, plans, and diagrams. Assist superintendent and foreman.

Safety engineer: Assemble apparatus men and arrange for rescue and firefighting operations.

Where the local organization is too limited to carry on all the emergency duties there will usually be enough assistance from neighboring mines or from agencies connected with accident-prevention activities, such as safety engineers of insurers and field safety personnel of the Federal Bureau of Mines.. Large companies will usually have an adequate staff for the more extensive organization that would be needed to handle a disaster or emergency at their mines. A detailed discussion of this subject is given in Miners' Circular 36 of the Bureau of Mines,[32] and particular attention is given to suitable local firefighting organization in the Advanced Mine Rescue Course offered to mine operators by the Bureau.

After men in the mine have been warned and mine officials have been notified of a mine fire, a temporary organization composed of the local mine officials and employees should be formed until experienced help arrives and a permanent organization can be effected. Where the fire is quickly controlled or can be handled with a small crew, the arrangements are simpler.

For fires that are serious and difficult to handle the following procedures should be given attention:

Checking in and out.—Arrangements should be made to obtain the check numbers or names, or both, of any men who come out of a mine after a fire or an explosion. When recovery work is started, a reliable man or men should be designated to check men into and out of the mine.

Permanent organization.—After the arrival of assistance, such as State mine inspectors, Federal Bureau of Mines representatives, mine officials, oxygen breathing-apparatus crews, workmen from other mines and companies, and others, a permanent organization should be formed. This permanent organization should take over and carry on the work started by the temporary organization, perform any other necessary functions that might have been overlooked by the temporary organization, and complete the recovery work in the safest and speediest possible manner.

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[31] Forbes, J. J., and Grove, G. W., Procedure in Sealing and Unsealing Mine Fires and in Recovery Operations Following Mine Explosions (revised May 1948): Bureau of Mines Miners' Circ. 36, 1948, p. 4.

[32] See footnote 31.

Man in charge of operations.—The permanent organization should be headed by a cool, competent mining man well versed and experienced in the technique of rescue and recovery work. The man in charge should have complete authority, and while off duty or away from the mine he should delegate his authority to one or more selected persons, so that someone who will be recognized as in charge will be available at all times. In addition to the man in charge of operations, there should be assembled an advisory committee of mining men thoroughly experienced in recovery operations, more or less conversant with local conditions, and also well versed in procedure and in the use and limitations of protective and detective apparatus and devices necessary for the safety of those engaged in the recovery operations.

A plan for the safe conduct of the work should be formulated by the man in charge or members of his advisory committee as soon as they have considered the situation and formed their conclusions. There should be no essential deviation from the plan as outlined unless such change is approved after careful consideration by those in charge.

Man in charge of shift.—A man experienced in mine rescue and recovery work should be in charge of each underground shift as assistant to the man in charge of all recovery operations. He should be well versed in mining work, especially in ventilation, mine gases, detective and protective equipment, and procedure following fires or explosions. One or more competent assistants and such other personnel as may be necessary to conduct recovery work safely and efficiently should be assigned to the man in charge of the shift. If exploratory and other work is being done by oxygen breathing-apparatus crews, the man in charge of the shift or one of his assistants should always be at the fresh-air base.

The man in charge of the shift should be provided with an up-to-date mine map on which should be marked, as the work progresses, the areas explored, ventilation restored, and location of bodies, locomotives, cars, pumps, falls, and other important data.

Oxygen breathing-apparatus and gas-mask crews.—Well-trained crews, physically fit and experienced in the use, limitations, and care of oxygen breathing apparatus and gas masks, are an essential part of any organization engaged in rescue and recovery. The extreme risk of using untrained, inadequately equipped men on the work is unquestioned by those familiar with its dangers.

Material crews.—Material crews, in charge of a foreman, should be provided to handle and transport promptly and efficiently material such as boards, timbers, nails, food, coffee, water, and other supplies from the mine portal or shaft bottom to the advance crews.

Miscellaneous crews and personnel.—Miscellaneous underground crews, such as timbermen, laborers to clean up falls, electricians to install and extend telephones, stretcher bearers (if required), and others if necessary should be readily available and in charge of foremen.

General headquarters.—A room or building near the mine entrance should be utilized as headquarters for the man in charge of operations and his assistants; it should have tables, chairs, and telephones connected with those being used underground and on the surface around the mine. Telephone attendants should be on duty at all times, and two or more men should be available at general headquarters for errand duty and messenger service where the telephone service is not at hand.

An up-to-date mine map should be provided and all important data noted on it to indicate the progress of recovery operations. The men in charge of different shifts, foremen of crews, and other supervisors should report progress to the general headquarters at the end of each shift so that officials, inspectors, and others may be informed of what has been accomplished.

Information bureau.—Relatives and friends of persons injured, killed, or missing in a mine disaster naturally are vitally concerned in the recovery work. The public is also interested in the property damage, loss of life, and progress of recovery operations, particularly the rescuing of live men or recovery of bodies. An information bureau to issue news to friends and relatives of entombed men and to the press and public should be established. It should be directed preferably by a local mine or other company official or State inspector. An authentic information bureau relieves anxiety and grief of relatives and friends, prevents injurious comment by outsiders, and obviates criticism and misleading statements by the press. All information should be issued by an authorized mine official or a representative of the State department of mines.

TRAINING AND PRACTICE

Where fires in surface structures may endanger men in the mine or those working in the surface plant, provision should be made at ordinary times or before a fire or explosion occurs both for fire-fighting equipment and for trained men who are immediately available to use this equipment. Where fire-fighting equipment is provided for the protection of surface plants, men should be trained in its use, both for their own safety and to avoid mistakes and delays likely to occur with uninstructed and untrained men.

Local mine officials, including surface officials, from time to time should receive instruction and training in the duties they are to perform individually and collectively should a mine fire or explosion occur. They should be informed where tools, equipment, and materials may be obtained quickly at the mine and from adjoining mines, jobbers, or stores. All officials should be instructed that, in the absence of superior authority, they are to attend promptly to the most important things and notify immediately, according to a list that should be kept available, all persons who may be able to assist at a disaster, particularly the State mine inspector having charge of the district in which the mine is located, oxygen breathing-apparatus crews, doctors, the Federal Bureau of Mines, and others.

Members of oxygen breathing-apparatus crews should be selected carefully and should receive thorough training and instruction in the use and care of oxygen breathing apparatus and in rescue and recovery procedure. They should be physically able to perform strenuous labor while wearing oxygen breathing apparatus and should have good judgment and a cool, calm disposition. Persons who are physically weak or of an excitable disposition are a menace to the safety of themselves and their coworkers as well when they try to engage in rescue or recovery work in toxic atmospheres. To assure that apparatus crews are physically fit, they should undergo a physical examination twice a year.

Persons trained in mine rescue work should have additional training in the use and care of oxygen breathing apparatus from time to time to keep fit for actual work. The Bureau of Mines recommends that each person receiving his mine rescue certificate take additional training at least once every 6 months. Additional training should consist largely of constructing bulkheads, setting timbers, carrying materials, and working out mine rescue problems while actually wearing oxygen breathing apparatus. The crews should be conducted into an irrespirable atmosphere as a part of each training to insure that men and equipment are in condition for an emergency.

Some training facilities are shown in figures 19, 20, 21, and 22.

Underground foremen and shift bosses should be included in the discussion and practice on problems affecting their section of the mine. Each boss should plan the action to be taken if a fire or other disaster should occur in his section; such plans should be specific, based on

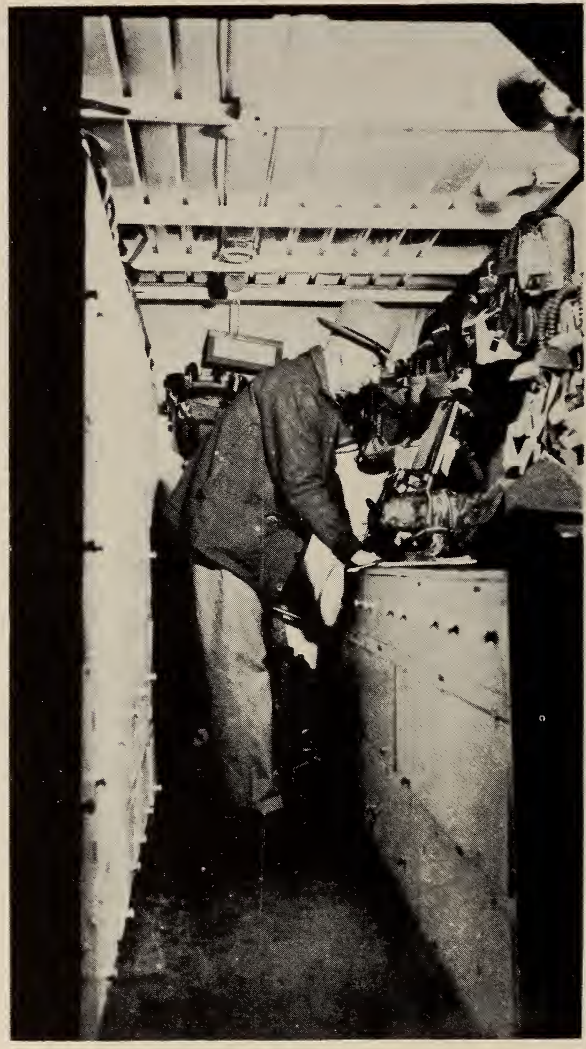

FIGURE 19.—Interior of Mine Rescue Truck, Idaho.

actual problems involving working places, travel and air ways, and crews and equipment for which he is responsible.

Examples of training procedures in various mining regions follow.

Approximately 175 men are continually being retained in the Coeur d'Alene mining district of Idaho by the director of the central mine rescue station in accordance with Bureau of Mines requirements. Practice training is conducted regularly at 3-month intervals, and the men receive a physical examination once each year to determine their physical fitness. At that time a Bureau of Mines representative examines the men and has them wear the apparatus in an irrespirable atmosphere for renewal of their certificates.

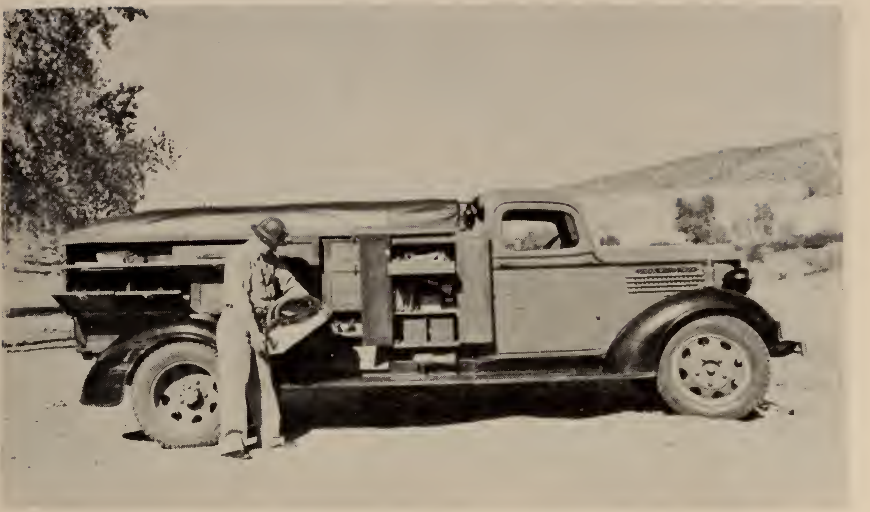

FIGURE 20.—Exterior of Mine Rescue Truck, Arizona.

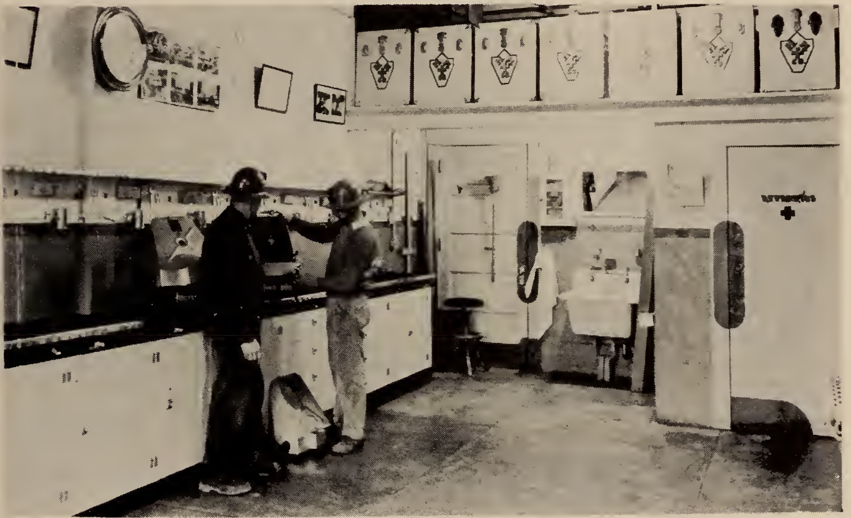

FIGURE 21.—Interior of Mine Rescue Station, Arizona.

At Butte, Mont., rescue men are regularly retained by company instructors. A good training tunnel which can be filled with smoke for simulating underground problems is provided.

In the Lake Superior district there were about 860 trained men at 57 active underground mines operated during 1953 by 12 mining companies. These men are cooperatively trained by company and Bureau of Mines instructors. Training periods generally are conducted at 6-month intervals for individual crews both underground and on the surface. Each mine has access to nearby mine rescue equipment, and the cooperation between companies is excellent.

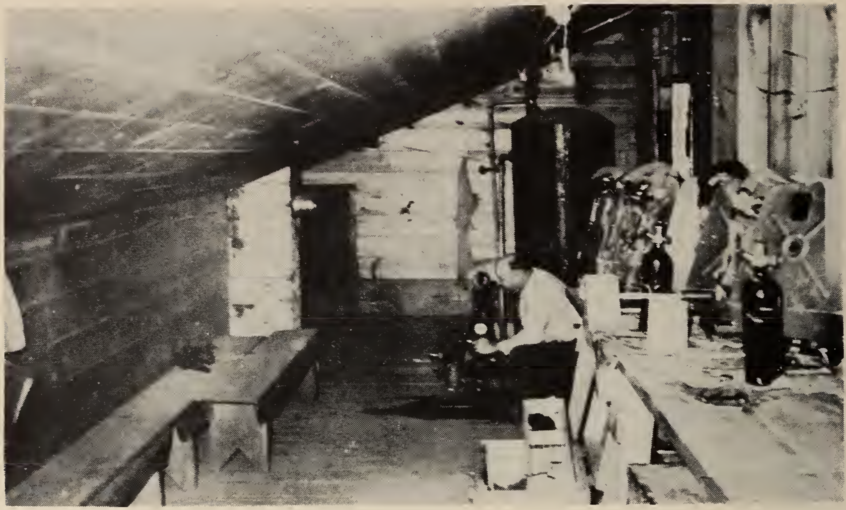

FIGURE 22.—Underground Mine Rescue Station, Idaho.

FIRE PREVENTION

HOUSEKEEPING

Fires have been started in mines for lack of even ordinary precautions in disposing of waste material. In 1928, 39 men were asphyxiated in the Hollinger mine, Ontario, Canada, by the smoke and fumes from a refuse fire in an old stope. Dry explosive-magazine refuse was dumped into an empty stope without concurrent backfilling or covering with broken rock.

Several mine fires have occurred in recent years in Idaho in underground lunchrooms from lunch papers being allowed to accumulate on the floor and coming in contact with an electric heater after the men returned to work. As lunchrooms are usually near the shaft station, it is highly important that all combustible materials, including paper, be properly disposed of. In a lunchroom the sandwich paper should be kept in a closed metal receptacle and taken outside the mine.

Oily waste, papers, waste carbide, explosives containers, and similar flammable debris should not be allowed to litter a mine but should be removed to the surface. Old timber waste should be gathered and preferably sent to the surface or possibly buried under the rockfilling material in old workings. Keeping a mine clean may save lives and thousands of dollars in property damage.

Good housekeeping in and about surface plants helps to reduce the chances of fires being started and makes it easier to fight them, if they do start. Many fires have started in a relatively small quantity of flammable waste material or in supplies left in an exposed place, and other fires have been communicated to buildings or mine workings in the same way. Fire fighting has been hindered and even prevented where hydrants, valves, and hose reels were made inaccessible by piles of scrap or stock carelessly left around or over them. Figure 23 shows good housekeeping around a surface plant.

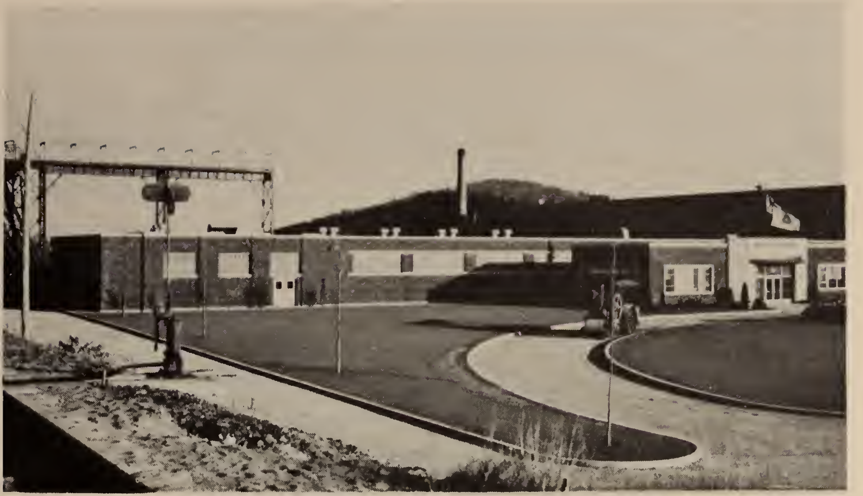

Figure 23.—Good Housekeeping Around a Surface Plant, Michigan.

LOCATION AND FIREPROOFING OF SURFACE BUILDINGS

Structures of wood or other flammable material adjacent to a shaft menace the lives of all men in the mine if they take fire, particularly if the shaft is wholly or partly downcast. Smoke or gases from such a building may be drawn into many, possibly all parts of the mine, and falling embers may set fire to the shaft timbering or to a timbered shaft station.

Headframes should be constructed of steel, but if they are made of wood they should be the open type and should be gunited or protected by using a good fire-retardant paint or compound. Flammable structures, other than open headframes, should be kept at least 100 feet from mine openings; if they are already adjacent to mine openings, they should be made fire-resistant by gunite, fire-retardant paint, or compound and thoroughly protected by readily available waterlines, hose, sprinkler systems, and fire extinguishers; the fire-extinguishing equipment should be kept in good working condition by periodical testing (figs. 24, 25, and 26).

FIREPROOFING IN SHAFTS AND UNDERGROUND

The Bureau of Mines recommends[33] "that the main intake shaft lining be of fireproof construction and that there be a minimum amount of flammable material in or adjacent to the shaft" and "that the main intake and main return air currents in mines be in separate shafts, slopes, or drifts." Fireproofing of the intake shaft is recommended to provide a safe means of exit in the event of fire. If a mine has only a single shaft opening partitioned for intake and return air, smoke from a fire in the mine will almost invariably work around

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[33] Mine Safety Board, Recommendations of the United States Bureau of Mines on Certain Questions of Safety as of February 3, 1933: Bureau of Mines Inf. Circ. 6732, 1933, 43 pp.

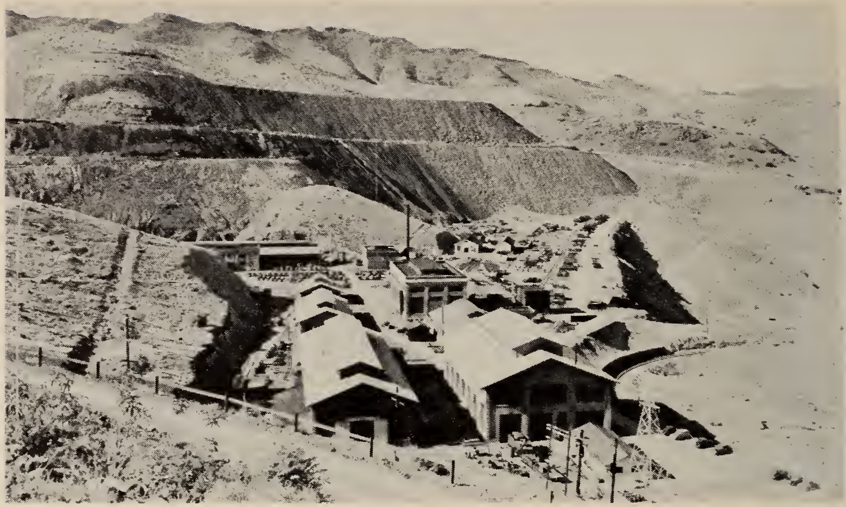

FIGURE 24.—Surface Plant, Fire-Resistant Construction.

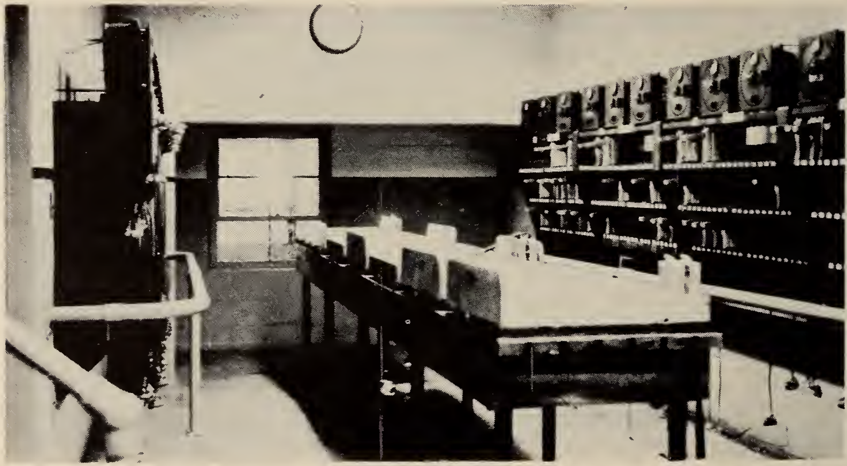

FIGURE 25.—Fire-Resistant Lamp Room, Idaho.

to the intake side of the partition and prevent exit, and a surface fire near the shaft will prevent entrance to either shaft compartment.

Where existing shafts are timber-lined, experience has shown that such timber can be made fire-resistant by applying cement or gunite. Some companies have found that gunite conceals and does not prevent timber decay; experience differs on this point; perhaps the condition of the timber and its age when gunited are important factors. Timber in electrical stations and about electrical equipment, such as auxiliary fans or blowers and pumps, should be made fire-resistant. Guniting may help in preventing the swelling of ground.

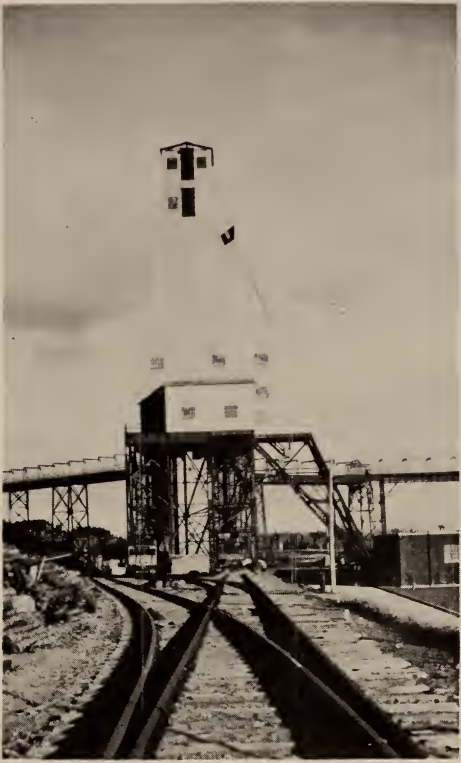

FIGURE 26.—Fire-Resistant Headframe, Michigan.

Timber can be treated with a number of chemicals that tend to make it both fire- and decay-resistant; among these are zinc chloride, borax, sodium fluoride, copper sulfate, and zinc-meta-arsenite. Some are water-soluble, hence not desirable for use in timber in wet places. In general, pressure treatment of seasoned wood by these preservatives is more effective than merely covering the timbers with paint by using a brush.

Many precautions and preventive means are employed to reduce the fire hazard when wood or other combustible materials are used for construction or ground support in mines and mine surface plants. A little-known and effective method of making such materials fire resistant is by spraying or brushing them with a fire-retardant compound or solution.[34] The fire-retardant chemical coatings and solutions now commercially available are a valuable means of providing additional fire protection at mines. Individual products must be selected with care. (Firex and ALBI–R gave 100-percent protection.)

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[34] Qopes, P. E., Fire-Retarding Paints and Compounds for Use on Mine Timers: Pres. before Nat. Safety Cong., Chicago, Ill., Oct. 20–24, 1952, 13 pp.

INSPECTION AND PATROLLING

The surface buildings of mine plants and parts of the underground workings susceptible to fire should be inspected regularly to discover any places that may have developed a serious fire risk. When this risk is realized, action should be taken to correct it by removing or fireproofing some or all of the flammable material or by guarding against whatever sources of ignition there may be. Inspections of this type are regular and decidedly worthwhile functions of fire-prevention officials in communities, industrial plants, and public service units. Although similar inspections are made at some mines by operating officials or by insurance-company inspectors, in many instances they are not thorough and recommended improvements are neglected. Certain fire risks may be accepted when lives are not endangered, but at least the inspections should be made so that the risks are known.

Where defective conditions are known and where property is unprotected by the presence of employees on their regular duties, patrols should be made so that incipient fires can be extinguished before they get beyond control. Automatic alarms or sprinkler systems may often be more effective than patrols, and it is likely that such installations should be more widely used in mining operations than they are at present.

Specific examples of inspection and patrolling by individual companies follow:

1. A continuous carbon monoxide sampler is connected to the hoist room and mine office to sound an alarm automatically in the event of an incipient mine fire.
2. Fire patrols go through each mine after the shift preceding any idle period, and, except where it is absolutely necessary, all electric power is cut off during the idle periods.
3. Welding and cutting areas are patrolled for at least 8 hours after the work is completed.

GUARDING AGAINST IGNITION

One common method of preventing fires is to remove or exclude sources of ignition from places where the surroundings are exceedingly flammable. Of the various causes of mine fires discussed here, electric arcs, open lights, matches, heating appliances, and welding equipment are the most common sources of ignition. The following standard recommendations are made by fire-prevention authorities as a result of experience and study.

In locations where there are flammable vapors, gases, or dusts, vaporproof lamps should be installed, and wiring should be of a type approved by the National Electric Code. Switches should be at a safe distance from places where these dangers prevail.

All light and power circuits should be provided with fuses or other protective devices of proper type and size; the circuits should not be overloaded. Circuit breakers should be installed on all main and branch powerlines not protected by fuses; they should be set as low as is practicable with the maximum demand of the equipment operated from that line.

Electric wiring should be installed in accordance with a method recognized as suitable for the purpose by the National Electric Code. Defective electric wiring should be repaired promptly to conform to the standards of the code.

Conductors whose insulation is unserviceable because of age, mechanical injury, or exposure to heat, moisture, or vapors should be replaced without delay.

Wiring installed for temporary use should be replaced or removed.

All joints of wiring should be properly soldered and taped.

Conductors of "open wiring" systems should not be in contact with each other or with pipes, woodwork, or other combustible material.

All extension lights should be provided with suitable wire guards. Extension cords should not be left in contact with pipes, nails, or combustible materials.

Doors or covers of fuse and switch cabinets should be kept closed.

To prevent heating, switches should make good contact and should not be overloaded. Where oil switches are used, a nonflammable type of oil is preferable.

Starting resistance units of direct-current motors should be located away from combustible material, or the material should be suitably protected.

Smoking should be prohibited in the vicinity of readily flammable material of any kind.

Open lights or torches should not be taken into mines or into any location containing readily flammable material and should not be left unattended close to combustible material.

Heating appliances should not be placed close enough to combustible material to scorch it. Woodwork should not be too near steampipes, boilers, flues, or furnaces.

Defective flues, stoves, furnaces, pipes, or chimneys should be replaced.

Ashes should not be brought into contact with combustible material.

Fixed welding and cutting operations should be confined within a well-ventilated fire-resistant area. Wood surfaces in this area should be protected with sheet metal or other incombustible material.

A suitable fire extinguisher should be carried with each portable welding or cutting unit. The area where the work is done should be wet down or wood surfaces protected when possible. The area should be inspected for evidence of any fire by a designated person 30 minutes after work has been completed.

Metal containers with self-closing covers should be provided for oily rags and other waste material.

GASES IN METAL AND NONMETALLIC MINES

GASES ENCOUNTERED—HAZARDS

Pure, dry air at sea level contains the following gases:[35] Oxygen (O_2), 20.95 percent; nitrogen (N_2), 78.09 percent; carbon dioxide (CO_2), 0.03 percent; and argon (A), 0.93 percent by volume. Traces of helium (He), neon (Ne), krypton (Kr), and xenon (Xe) are also present, but these gases, as well as argon, are usually included with nitrogen because they are chemically and physiologically inert and for practical purposes may be considered as part of the atmospheric "nitrogen." Mine air also contains 1 percent or more of water vapor, depending on the temperature, barometric pressure, presence of liquid water to form the vapor, and the moisture content of the intake air entering the mine. The weight of a gas or a mixture of gases varies with the temperature and pressure and, to a slight extent, with the associated water vapor in the air. Dry air at sea level at 70° F. weighs 0.075 pound per cubic foot,[36] a figure that is quite generally used as a standard for air density. The specific gravity of a gas or a mixture of gases is the ratio of the weight of a specific volume of the gas to the weight of an equal volume of air at the same temperature and pressure. Thus, the specific gravity of air is stated arbitrarily to be 1. The specific gravity of a gas lighter than air is less than 1 and of a gas heavier than air is greater than 1.

The quantities of air breathed and of oxygen consumed by average-size men at rest and exercising both moderately and vigorously[37] are given in table 5.

Certain gases occur in metal and nonmetallic mines much more commonly than is ordinarily supposed. Some of these gases occur naturally in the rock or earth; others are formed by chemical action in the mine workings or are products of mine fires, explosions, or blasting. A brief description of the common gases follows.

TABLE 5.—*Approximate rate and volume of respiration and of oxygen consumed by man*

Degree of activity	Respirations per minute	Air inhaled per respiration, cubic inches	Air inhaled per minute, cubic inches	Oxygen consumed per minute, cubic inches
At rest	15 –17.1	28–37	470–634	14–20
Moderate exercise	14.7–19.5	78–252	1,135–3,715	48–155
Very vigorous exercise	27 –33	140–163	3,780–4,700	129–195

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[35] Humphreys, W. J., Physics of Air: McGraw-Hill Book Co., Inc., New York, N. Y., 3d ed., 1940, p. 67.

Forbes, J. J., and Grove, G. W. (revised March 1954 by McElroy, G. E., Watson, H. A., Coggeshall, E. J., Dornenburg, D. D., and Berger, L. B.), Mine Gases and Methods for Detecting Them: Bureau of Mines Miners' Circ. 33, 1954, 82 pp.

[36] McElroy, G. E., Engineering Factors in the Ventilation of Metal Mines: Bureau of Mines Bull. 385, 1935, 196 pp.

[37] Henderson, Y., and Paul, J. W., Oxygen Mine Rescue Apparatus and Physiological Effects on Users: Bureau of Mines Tech. Paper 82, 1917, 93 pp.

NITROGEN

Nitrogen (N_2) is a colorless, odorless gas slightly lighter than air, which when breathed suffocates a human being in much the same way that water does. Mixed with oxygen in the approximate percentage of 79 to 21, as in ordinary air, it dilutes the oxygen and is breathed normally. It is not combustible and will not support combustion. High-nitrogen gases sometimes issue from the strata in metal mines.

CARBON DIOXIDE

Carbon dioxide (CO_2) is a product of oxidation and combustion of organic compounds and of the respiration of men and animals. It is a heavy, colorless, and odorless gas often found mixed with nitrogen in unventilated workings, particularly in dips and winzes. It will not burn or support combustion. It has been found emanating from the rock strata in underground workings of certain mines, notably in the Cripple Creek, Colo., and Tintic and Park City, Utah, districts, as well as in numerous other metal-mining regions.[38] Carbon dioxide is a constituent of blackdamp, and traces of it (0.03 percent) are always present in normal air.

Carbon dioxide is a respiratory stimulant. It is therefore physiologically active and cannot be classed with inert gases, although it is not highly toxic.[39] Its property of stimulating breathing is utilized in certain resuscitation apparatus.

One half of 1 percent (0.5 percent) of carbon dioxide in normal air causes a slight increase in lung ventilation; a man exposed to this percentage of carbon dioxide will breathe a little deeper and a little faster than when in pure air. If the air contains 2 percent of carbon dioxide, the lung ventilation will be increased about 50 percent; if the air contains 5 percent, it will be increased about 300 percent, and breathing is laborious; and 10 percent cannot be endured for more than a few minutes.[40] Carbon dioxide in air has these effects when the oxygen content remains about normal and the subject is at rest. Moving around or working would naturally increase the symptoms, and they would be much more dangerous than when a man is resting.

Low oxygen content of the air and temperatures above 80° F. increase the effect of carbon dioxide so that serious effects may be felt at lower concentrations than those given. Concentrations of more than 5 percent of carbon dioxide are usually accompanied by an appreciable lowering of the oxygen.

Solid (dry ice) or liquid carbon dioxide sublimes at 109.3° F. below zero.[41] Liquid carbon dioxide is employed in a special permissible cartridge for blasting coal,[42] and dry ice has been used as a source of inert gas for extinguishing mine fires.

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[38] McElroy, G. E., Rock-Strata Gases in Mines of the East Tintic Mining District, Utah: Bureau of Mines Rept. of Investigations 2275, 1921, 3 pp.

Denny, E. H., Marshall, K. L., and Fieldner, A. C., Rock-Strata Gases in the Cripple Creek District and Their Effect on Mining: Bureau of Mines Rept. of Investigations 2865, 1928, 24 pp.

[39] Bureau of Mines, Some Pertinent Information About Mine Gases: Inf. Circ. 6983, 1938, 15 pp.

[40] Committee, International Mine Rescue Standardization Conference, Mine Rescue Standards, a Tentative Study: Bureau of Mines Tech. Paper 334, 1923, 44 pp.

[41] International Critical Tables, McGraw-Hill Book Co., Inc., New York, N. Y., vols. 1 and 3, 1928.

[42] Tiffany, J. E., A New Permissible Blasting Device: Bureau of Mines Rept. of Investigations 2920, 1929, 8 pp.

Air in which men work or travel in mines should be improved when it contains less than 19.5 percent of oxygen, more than 0.5 percent carbon dioxide, or is contaminated with combustible, noxious, or poisonous gases.

CARBON MONOXIDE

Carbon monoxide (CO) is the gas responsible for more than 90 percent of the fatalities from mine fires; it is not present normally in air but is formed in the burning of any combustible carbonaceous substance, such as timber, explosives, or petroleum products, especially where there is smoldering or incomplete combustion. It is found in the exhaust gases of internal-combustion engines and in gases generated by explosives. Carbon monoxide is a colorless, odorless gas slightly lighter than air. The most important characteristic of carbon monoxide is it poisonous or asphyxiant action upon man, even in very low concentrations. Carbon monoxide is combustible, and air that contains 12.5 to 75 percent of carbon monoxide will explode if ignited.[43]

Carbon monoxide can be detected with various types of carbon monoxide detectors and by use of canaries and mice, but it cannot be detected with the flame safety lamp until the concentration becomes so high that persons without respiratory protective equipment would be overcome almost immediately.

The main effect of carbon monoxide on the body is that it combines with the hemoglobin of the blood and prevents the hemoglobin from carrying oxygen to the tissues. The affinity of carbon monoxide for hemoglobin is about 300 times that of oxygen.

The more common effects of mild carbon monoxide poisoning are shortness of breath, headache, dizziness, muscular weakness, and nausea. Occasionally exposure to this gas causes loss of memory and visual, speech, and hearing disturbances and even psychoses, neuritis, and paralysis. However, these effects result only from the most severe exposure and usually after prolonged unconsciousness.

The physiological effects of various concentrations of carbon monoxide and significance of time exposure, as recognized by the Bureau of Mines and the National Safety Council, are given in table 6.

TABLE 6.—*Physiological effects of carbon monoxide*

Concentration of carbon monoxide, percent by volume	Physiological effects
0.01	Nonappreciable effect after several hours of exposure.
.02	Symptoms of mild poisoning (headache) after 1½ hours of exposure.
.04–0.05	Symptoms of poisoning in ¾ to 1 hour; headache, nausea, and unconsciousness in 1½ to 2 hours; dangerous to life after 2 hours.
.08–0.10	Unconsciousness after 1 to 1½ hours of exposure; death after 2 hours.
.15–0.20	Severe headache, nausea, and unconsciousness in ½ to 1 hour; fatal after 1 hour.
.40 or more	Fatal if breathed for a short period.

The generally recognized maximum allowable concentration[44] for an 8-hour exposure to air containing carbon monoxide and the normal quantity of oxygen is 0.01 percent (100 parts of carbon monoxide per million parts of air, by volume).

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[43] Coward, H. F., and Jones, G. W., Limits of Flammability of Gases and Vapors: Bureau of Mines Bull. 503, 1952, 155 pp.

[44] American Medical Association Archives of Industrial Hygiene and Occupational Medicine, Threshold Limit Values for 1953: Vol. 8, 1953, pp. 296–297.

OXYGEN

Oxygen (O_2) is the gas in air that supports life and combustion. It is colorless, odorless, nonpoisonous, heavier than air, and the most important to man of all the gases in air. Men breathe most easily and work best when the air contains about 21 percent of oxygen, the amount usually present in air. Yet they can live and work, though not so well, when there is less oxygen.

When ventilation is inefficient, the air in various parts of a mine may be deficient in oxygen but high in carbon dioxide. The Bureau of Mines recommends that mine air be considered unfit for men to breathe if it contains less than 19 percent of oxygen.[45] The flame of a lighted candle or a flame safety lamp is extinguished when the air contains about 16.25 percent of oxygen, and the flame of a carbide lamp is extinguished when the air contains about 12.50 percent. Work may be continued in air containing less than 16.25 percent, but on exposure to concentrations between 16.25 and 12.50 percent the blood cannot absorb oxygen fully, the higher centers of the brain are affected, and the judgment is impaired. Although men do not lose consciousness until the oxygen content is very much less than 13 percent, no one should try to enter or remain in an atmosphere in which a flame safety lamp or candle will not burn unless he wears a self-contained breathing apparatus.

Pure oxygen, as used in oxygen breathing apparatus at atmospheric pressure (15 p. s. i. at sea level), may be inhaled from 7 to 40 hours without ill effects.[46] Although the effects of increased concentrations of oxygen at atmospheric pressure are characterized mainly by lung irritation and other pulmonary involvements, inhalation of oxygen at higher pressures produces symptoms of the central nervous system. At pressures of oxygen greater than 2 atmospheres the effects on the central nervous system reportedly predominate. Symptoms of oxygen poisoning produced by high partial pressures of oxygen are convulsive seizure of the head, neck, and limbs, irregular and labored breathing, nausea, and in some cases apnea or complete temporary cessation of breathing.

The hazard of wearing oxygen breathing apparatus in caisson or subaqueous tunneling operations should be taken into consideration. The following tabulation gives the duration of breathing oxygen under pressure that may be tolerated by man.

Oxygen pressure atmospheres	*Time limit of exposure,*[1] *without ill effects, hours*
1	7–40
2	0. 75– 3
3	0. 5– 2
4	0. 2–0. 7
7	0. 1
9	0. 05

[1] Most authorities agree that 24 hours' exposure produces no ill effects.

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[45] Mine Safety Board, Recommendations of the United States Bureau of Mines on Certain Questions of Safety as of October 1936: Bureau of Mines Inf. Circ. 6946, 1937, p. 15.

[46] Berger, L. B., and Davenport, S. J., Effects of the Inhalation of Oxygen: Bureau of Mines Inf. Circ. 7575, 1950, 36 pp.

METHANE

Methane (CH_4), the explosive gas frequently found in coal mines, occurs also in some metal and nonmetallic mines. It is colorless, odorless, tasteless, nonpoisonous, and flammable. The physiological effects closely resemble those resulting from nitrogen; hence, it is not harmful when inhaled, unless because of its presence, the oxygen content of the air is lowered beyond a safe percentage.

Air containing 5 to 15 percent of methane and 12.1 percent or more of oxygen will explode if ignited.[47]

Methane may be detected with the flame safety lamp or a methane detector.

HYDROGEN SULFIDE

Hydrogen sulfide (H_2S)—called "stinkdamp" from its odor, which resembles that of rotten eggs—is a colorless gas heavier than air and is usually a product of the decomposition of sulfur compounds.[48] It may be produced also by burning explosives containing sulfur and may be liberated in using black blasting powder or dynamite to blast sulfide ores. Hydrogen sulfide occurs in many gypsum mines.

This gas is extremely poisonous, and small quantities rapidly dull the olfactory nerves, but fortunately it can be detected by its odor before a dangerous concentration is reached; it presents the possibility of poisoning wherever it exists. The physiological effects attending exposure to various concentrations of hydrogen sulfide in air are given in table 7.[49]

The generally recognized maximum allowable concentration of hydrogen sulfide in the air of working places is 0.002 percent by volume (20 parts hydrogen sulfide per million parts of air) during an 8-hour exposure.[50]

When hydrogen sulfide gas is detected, the ventilation should be improved immediately.

TABLE 7.—*Physiological effects of hydrogen sulfide*

Concentration of hydrogen sulfide, percent by volume	Physiological effects
0.005–0.010	Subacute poisoning—slight symptoms, such as mild conjunctivitis (eye irritation) and irritation of respiratory tract after 1 hour of exposure.
.02– .03	Subacute poisoning—marked conjunctivitis and irritation of respiratory tract after 1 hour of exposure.
.05– .07	Subacute poisoning—dangerous in ½ to 1 hour.
.07– .10	Possible acute poisoning—rapid unconsciousness, cessation of respiration, and death.
.10– .20 or more	Acute poisoning—rapid unconsciousness, cessation of respiration, and death in a few minutes.

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[47] Coward, H. F., and Jones, G. W., Limits of Flammability of Gases and Vapors: Bureau of Mines Bull. 503, 1952, 155 pp.

[48] Sayers, R. R., Mitchell, C. W., and Yant, W. P., Hydrogen Sulfides as an Industrial Poison: Bureau of Mines Rept. of Investigations 2491, 1923, 6 pp.

[49] Yant, W. P., Hydrogen Sulfide in Industry: Occurrence, Effects, and Treatment: Am. Jour. Pub. Health, 1930, vol. 20, pp. 598–608.

[50] See footnote 44.

SULFUR DIOXIDE

Sulfur dioxide (SO_2) is a colorless, nonflammable, suffocating, irritating gas heavier than air, with a strong, pungent sulfurous smell. It is sometimes formed in the blasting of certain sulfide ores and may be evolved by gob or cave fires in which iron pyrite is burning.

Sulfur dioxide is strongly irritating to the eyes, nose, and throat, even in low concentrations, and can cause severe damage to the lungs if inhaled in high concentrations, although such concentrations may cause respiratory paralysis and inability to breathe immediately upon inhalation. High concentrations of the gas (1 percent or more) are irritating to moist areas of the skin.

Sulfur dioxide may be a serious hazard in blasting massive sulfides; such operations likely would produce other harmful gases, such as hydrogen sulfide and carbon monoxide. Several instances are on record where the combined effects resulted in serious irritation of bronchial passages and lungs, with fatal results a few hours later. Similar combinations of gases are formed by fires in sulfide ores; analyses of gases from such fire areas have shown 0.04 to 0.12 percent of sulfur dioxide.

The physiological effects of various concentrations of sulfur dioxide in air are given in table 8.[51]

TABLE 8.—*Physiological effects of sulfur dioxide*

Concentration of sulfur dioxide, parts per million parts of air	Physiological effects
0.3–1	Detectable by most persons by sense of taste rather than by odor.
3–5	Detectable odor.
10	Maximum concentration allowable for prolonged exposure.
20	Least amount causing coughing and immediate irritation of the eyes.
50	Pronounced irritation of eyes, throat, and lungs but may be endured several minutes.
50–100	Maximum concentration allowable for short exposure (½ to 1 hour).
150	Extremely disagreeable but may be endured several minutes.
400–500 (0.04 to 0.05 percent by volume).	Dangerous for even short exposure; may be impossible to breathe.

OXIDES OF NITROGEN

Oxides of nitrogen (NO, NO_2, etc.) are formed in mines by burning, by afterburning, and, under certain conditions, by detonation of explosives. They are also components of the exhaust of diesel and gasoline engines and are formed by the reaction of atmospheric oxygen and nitrogen in air in close proximity to electric sparks and arcs. Oxides of nitrogen are produced also by the burning or decomposition of nitrates and nitrated materials. Nitrogen forms several oxides—N_2O, NO, NO_2, N_2O_4, N_2O_3, and N_2O_5. All of these are toxic except nitrous oxide (N_2O). The most commonly occurring toxic oxides of nitrogen are nitric oxide (NO) and nitrogen dioxide, which occurs in two forms (NO_2 and N_2O_4), depending on the existing temperature.

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[51] Henderson, Y., and Haggard, H. W., Noxious Gases and Principles of Respiration Influencing Their Action: Reinhold Pub. Co., New York, N. Y., 1943, 294 pp.

Patty, F. A., Arsenic, Phosphorus, Selenium, Sulfur, and Tellurium; chap. in Industrial Hygiene and Toxicology: Interscience Publishers, Inc., New York, N. Y., vol. II, 1949, p. 584.

When air samples are analyzed for oxides of nitrogen, the results usually are reported in terms of nitrogen dioxide (NO_2), as such designation gives proper evaluation of the toxic properties of the atmosphere. Nitrogen dioxide is heavier than air and brownish red but may not be visible in dimly lighted places or in low but toxic concentrations.

The toxic oxides of nitrogen dissolve in the moisture in the lungs, forming nitrous and nitric acids, which corrode the respiratory passages, and the breathing of relatively small quantities may prove fatal. The effect is unlike that of carbon monoxide in that a person may apparently recover from exposure to oxides of nitrogen and then suddenly die several hours or days later. Table 9 presents the physiological effects reported for various concentrations of oxides of nitrogen.[52]

When high explosives burn, high concentrations of oxides of nitrogen may be formed; hence, gases from burning high explosives should not be breathed without adequate respiratory protection. Hall and Howell [53] report that gases collected in a Bichel gage from burning 40-percent gelatin dynamite contained 11.9 percent of oxides of nitrogen.

The Bureau of Mines has on record an instance in which explosives detonated incompletely and in large part burned, giving off brownish-yellow fumes; 13 men were affected by the smoke and fumes from the explosives, but all revived upon reaching fresh air. Within a short time, however, symptoms of bronchial and lung irritation developed, and in 3 days 9 of the 13 men had died; the remaining 4 did not recover for several months.[54]

The physiological effects of oxides of nitrogen are shown in table 9.

TABLE 9.—*Physiological effects of oxides of nitrogen*

Concentrations of oxides of nitrogen		Physiological effects
Parts per million [1]	Percent [1]	
25	0.0025	Maximum allowable for prolonged exposure.[2]
60	.006	Least amount causing immediate throat irritation.
100	.01	Least amount causing coughing.
100–150	0.01–0.015	Dangerous for even short exposure.
200–700	.2 –0.07	Usually fatal on short exposure.

[1] By volume.

[2] American Standards Association, American Standard Allowable Concentration of Oxides of Nitrogen: Z 37.13, 1944, 6 pp.

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[52] See footnote 51.

[53] Hall, C., and Howell, S. P., The Selection of Explosives Used in Engineering and Mining Operations: Bureau of Mines Bull. 48, 1914, 50 pp.

[54] Harrington, D., and Denny, E. H., Gases That Occur in Metal Mines: Bureau of Mines Bull. 347, 1931, p. 13.

DIFFUSION OF GASES

Facts regarding the diffusion of gases are important in connection with their presence in mines. Gases released into still air without mixing with air tend to stratify according to their respective densities. Light gases or mixtures tend to stratify against the roof or "back" and heavy gases or mixtures along the floor. In still air the ordinary process of diffusion, in accordance with Graham's law for the diffusion of gases, is a very slow process. However, under usual mine conditions or around mine fires ventilation currents and convection currents produced by temperature differences cause a rapid mechanical mixing of gases with air, and once mixed the gases do not separate or stratify.

Mixtures of low-oxygen, high-nitrogen gases that are lighter than air are sometimes found stratified against the back, particularly where the gases are warmer than nearby cooler air, so that a light that burns freely near the floor is extinguished when placed near the back. The opposite condition of a light burning freely near the back but extinguished near the floor is frequently encountered where low-oxygen, high-carbon dioxide gases stratify along the floor. This condition sometimes occurs in ventilated openings.

LOW-OXYGEN ATMOSPHERES

Blackdamp is a term generally applied to carbon dioxide, but this is a misapplication; it is an atmosphere depleted of oxygen rather than an atmosphere containing an excess of carbon dioxide. Blackdamp is found in abandoned or sealed mine workings and in wells. Generally, it is a mixture of carbon dioxide and nitrogen but may contain varying proportions of oxygen and methane.

Blackdamp is normally formed by the absorption or adsorption of oxygen by strata, timbers, men, animals, and open lights and the liberation of carbon dioxide by these agencies. Any atmosphere underground that will extinguish flame (except high percentages of methane) probably can be and usually is considered blackdamp.

ALDEHYDES

Chemically, aldehydes are oxidation products of primary alcohols. In mines aldehydes, along with carbon dioxide, carbon monoxide, and oxides of nitrogen, are undesirable constituents of diesel-engine exhaust gases and gases formed by the detonation and burning of explosives.

The odor and irritating effects of the exhaust gas of diesel engines are produced mainly by aldehydes,[55] which occur in the exhaust in varying amounts, depending on several factors, such as fuel-air ratio at which the engine is operating, design of the engine, engine temperature, and condition of the fuel-injection equipment of the engine. If the exhaust contains a high concentration of aldehydes, it is definitely irritating to the eyes and nasal passages; in fact, the irritating effects are more noticeable than the odor if one is exposed to a high concentration of the exhaust gas. If the exhaust is diluted with a large proportion of air, as in the general atmosphere of a ventilated mine or tunnel, the irritating effect is not evident, but a characteristic odor remains, even though the concentrations of the aldehydes in the air are extremely low.

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[55] Berger, L. B., Elliott, M. A., Holtz, J. C., and Schrenk. H. H., Diesel Engines Underground. VI. Use of Diesel Locomotives in Construction of the Delaware Aqueduct: Effect of Exhaust Gases Upon Quality of Tunnel Air: Bureau of Mines Rept. of Investigations 4032, 1947, pp. 19–20.

The threshold of odor occurs at an aldehyde concentration of approximately 0.2 to 0.3 p. p. m. by volume and the threshold of nasal and eye irritation at a concentration of about 1 p. p. m.[56]

It is the consensus of observers in the Health Branch of the Bureau of Mines that they would not choose to remain for any prolonged period in an atmosphere containing 10 p. p. m. of aldehydes.

SMOKE

Smoke consists of exceedingly small particles of solid and liquid matter suspended in the atmosphere. These particles are composed chiefly of soot or carbon and tarry substances. Smoke is irritating to breathe but is not in itself asphyxiating to any considerable degree. Asphyxiating and irritating gases and vapors, carbon monoxide, and products of distillation generally accompany smoke, and persons overcome thereby often attribute the effects to the visible smoke.

OCCURRENCE OF GASES IN MINES

Low-oxygen atmospheres high in carbon dioxide and nitrogen are formed in mines in several ways.

In the Rico district, Colorado, the occurrence of irrespirable gases in a metal mine was investigated by the Bureau of Mines.[57] Irrespirable gases have been found in this district virtually since mining was begun there and have frequently impeded work and constituted a hazard to miners' lives.

The ore is valuable chiefly for its silver and gold content. Considerable pyrite occurs in and near the vein; limestones, shales, and sandstones characterize the rock formation of the region. Gases that would extinguish the flame of a carbide lamp and have distinctive odors have been found in parts of a certain mine for years. About 1,700 feet from the portal of the fourth level was a vertical winze said to be 65 feet deep. At the time of the investigation the heat increased noticeably as one approached the winze, and there was a distinct odor of hydrogen sulfide at the top. The flame of a carbide lamp and that of a candle were extinguished at the top. Air samples were taken about 1 foot below the collar of the winze and analyzed. The analyses showed 49.2 percent of carbon dioxide, 10.8 percent of oxygen, and 40 percent of nitrogen but no methane. Although hydrogen sulfide gas was evidently present, as indicated by the characteristic odor of rotten eggs, the amount was too small to be disclosed by chemical analysis.

At the breast of the tunnel some air samples showed about 6.5 percent of carbon dioxide and 19.55 percent of oxygen. The amount of sulfur dioxide as determined by odor was too small to be determined analytically. A dry-bulb temperature of 99° and a wet-bulb temperature of 79° were recorded.

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[56] Elliott, M. A., Review of Bureau of Mines Work on Use of Diesel Engines Underground: Bureau of Mines Rept. of Investigations 4381, 1948, p. 24.

[57] Work cited in footnote 54 (p. 68), 21 pp.

The excessive heat in this mine, especially in the sections containing the irrespirable gases, points to the conclusion that chemical action accompanied by the liberation of heat was proceeding rapidly in the strata. It is believed that in this mine, as in some other mines investigated by the Bureau, the gases formed and heat produced result from the action of atmospheric air and mine water upon the sulfides and carbonates in the fissured rock.

Similar occurrences of gas were investigated in the Cripple Creek gold-mining district, Colorado.[58] Here the coroner's records show that at least 35 lives have been lost by suffocation in irrespirable gases during some 25 years of mining.

Much of the mining in this district is done in or adjacent to a porous breccia, and the veins mined are often fissured and open. This structure probably accounts for the fact that gases are liberated suddenly and in considerable volume from the strata upon a slight lowering of atmospheric barometric pressure and disappear again almost as quickly when the barometer rises and weather conditions clear.

In one gas occurrence investigated by the Bureau of Mines, in which two men lost their lives, air samples collected by means of vacuum bottles in the shaft showed less than 0.3 percent of oxygen, 18 percent of carbon dioxide, and 81 percent of nitrogen, although the air in this same shaft had been entirely free of gas a few hours earlier. One idle mine with extensive workings was entirely free of gas during good weather, but when a storm arose the mine filled with carbon dioxide and nitrogen so that the light of a carbide lamp was extinguished 20 feet outside the portal. Sulfur dioxide was detected only once and then by odor only.

The Bureau of Mines investigated the occurrence of rock-strata gases in the East Tintic mining district in Utah.[59] The gases found in these mines occurred mainly during low barometric pressure and changing weather conditions and caused much trouble until mechanical means of ventilation were introduced. Rock and air temperatures in these mines were abnormally high. Some of the gases contained more than 60 percent of carbon dioxide, whereas other gases were almost pure nitrogen and consequently so light that they accumulated in raises.

In several Nevada[60] mines gases high in nitrogen have been found to issue in quantities from freshly cut fissures. They are found in raises and have caused fatalities.

Fatalities have resulted from rock gases in Gilpin County, Colo.; Park City, Utah; Picher, Okla.; and many other metal-mining districts in the United States. Occurrences of irrespirable rock-strata gases in metal mines in England, France, New Zealand, and Australia have also been recorded.

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[58] Denny, E. H., Marshall, K. L., and Fieldner, A. C., Rock-Strata Gases in the Cripple Creek District and Their Effect on Mining: Bureau of Mines Rept. of Investigations 2865, 1928, 24 pp.

Denny, E. H., Marshall, K. L., Fieldner, A. C., Emery, A. H., Yant, W. P., and Selvig, W. A., Rock-Strata Gases of the Cripple Creek District, Colorado, and Their Effect on Mining: Bureau of Mines Bull. 317, 1930, 66 pp.

[59] McElroy, G. E., Rock-Strata Gases in Mines of the East Tintic Mining District, Utah: Rept. of Investigations 2275, Bureau of Mines, 1921, 3 pp.

[60] Gardner, E. D., Rock-Strata Gases in Mines of a Nevada Mining District: Rept. of Investigations 2427, Bureau of Mines, 1922, 4 pp.

In unwatering and reopening metal mines in various districts of California, mixtures of carbon dioxide and nitrogen have filled the openings as the water was removed. The gases appeared to come from the water as the depth was lowered and the pressure was reduced. After the water had been drained and the gases removed by ventilation, no further trouble was experienced. In the iron mines of the Lake Superior district there have been numerous fatalities from the apparently sudden filling of the upper parts of raises with irrespirable gases.

Carbon dioxide emitting from the surface material near the top of the Niobrara chalk formation caused a fatality in a large calyx hole in South Dakota.

Methane has been encountered in unwatering long-abandoned timbered mine workings.[61] An explosion occurred in an adit the morning after it had been opened into an old timbered shaft that had been flooded for years; after the water drained, the miners entered with open carbide lamps and when near the shaft ignited the gas. In reopening another shaft methane was found bubbling out of the water, and an explosion occurred when an open light was carried down in spite of regulations. The shaft and mine were entirely in granitic rocks. Many other occurrences of this nature are known; these are explained by the decomposition of timber under water, forming methane similarly to the formation of methane or marsh gas in swamps. Occurrences of methane in dewatering metal-mine workings (usually a shaft) have been encountered in several States.

Methane has been found in metal and nonmetallic mines of virtually all kinds, especially where rock formations are composed of carbonaceous material to any extent. Ignitions causing serious burns to miners have occurred repeatedly. Scarcely a year passes without one or more ignitions of methane in various types of non-coal-mine workings, including those where gold, silver, copper, iron, zinc, lead, limestone, salt, mercury, potash, and other metallic or nonmetallic substances are produced and frequently in tunnels or shafts driven in or around cities for water or similar purpose.

In the Grass Valley, Calif., gold-mining district, where carbonaceous shales occur in conjunction with or close to the gold-bearing measures, some rather extensive and troublesome accumulations of methane have been found.

Several ignitions of methane have occurred in the old Joplin lead-zinc district of Missouri and the newer Picher, Okla., district as well. Methane has been found also in at least one iron-ore mine in Alabama and in some quicksilver mines in California. Methane explosions have been started by open lights or matches in salt mines in New York and in Louisiana. Disastrous explosions have been started by ignitions of gas in asphalt mines in Oklahoma and ignitions of gas or dust, or both, in gilsonite mines of Utah.

Methane has been encountered in tunnels in sedimentary and in volcanic-rock formations; disastrous ignitions often resulted before the danger was appreciated and the necessary precautions taken.[62]

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[61] Harrington, D., An Unusual Hazard in Reopening Long-Flooded Timbered Metal Mines: Bureau of Mines Rept. of Investigations 2255, 1921, 3 pp.

[62] Harrington, D., and Ash, S. H., Some Essential Factors in Tunneling: Bureau of Mines Bull. 439, 1941, 61 pp.

The water pumped from an old copper mine in Michigan contained 1.3 to 7.0 percent methane by volume.

Sulfur dioxide and hydrogen sulfide are formed in blasting some sulfide ores; these gases are also released by mine waters, particularly in mercury mines, and are sometimes found in gypsum and coal mines.

GAS-DETECTION INSTRUMENTS

FLAME SAFETY LAMPS

Detectors of various types are used to test for the presence of these gases and to measure the concentration at any point. The flame safety lamp has been used in coal mines for considerably more than a century for the detection of methane and as a check on the amount of oxygen in the air (fig. 27). In principle, it is a lamp whose flame is completely enclosed and separated or protected from the outside air by means of a glass chimmey and wire gauzes that allow air to enter and burned

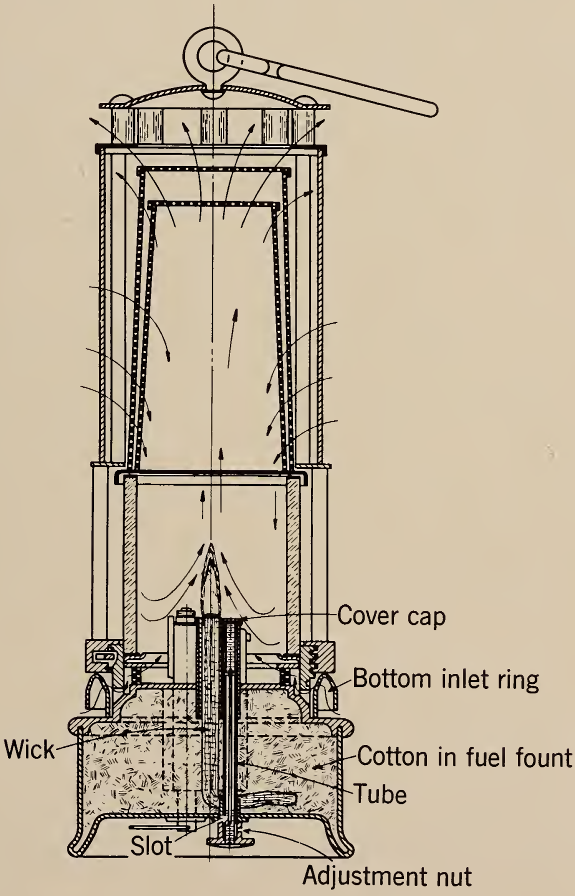

Figure 27.—Details of Flame Safety Lamp.

gases to escape but do not allow flame to be communicated to the outside atmosphere. Air containing combustible gas within the explosive limits may burn or explode within the lamp, but such an explosion cannot be transmitted through the wire gauzes to the outside atmosphere. The heat of the flame is absorbed by the wire gauze and radiated, cooling the flame to below the ignition temperature. The presence of combustile gas can be determined with fair accuracy by the height of the "cap" which forms on the flame up to the explosive limit of the gas, at which point the flame is extinguished. In addition to testing for combustible gas, the flame of this lamp is extinguished when the oxygen content of the air drops below 16.25 percent; this serves as a warning to men to return to good air.

The flame of a lighted candle or carbide lamp is also extinguished in atmospheres deficient in oxygen; the candle flame, like that of the flame safety lamp, is extinguished when the oxygen content falls below 16.25 percent, but the carbide lamp continues to burn until oxygen is below 12.50 percent. Although men seldom lose consciousness until the oxygen content of the air drops considerably below 13 percent, none should try to enter or remain in an atmosphere in which a flame safety lamp or a candle will not burn.

The use of an open light or flame in any place where conbustible gases are present or suspected is very hazardous. Numerous mine disasters have resulted, with great loss of life and heavy property damage, because of gas ignitions and explosions. Many mine fires have also occurred because combustible material such as timber has been ignited by flame from candles, carbide lamps, or matches used by smokers.

ELECTRIC METHANE DETECTORS

Dectectors of an electrical type determine the amount of explosive gas as well as indicate its presence. In general, they utilize the principle that the electrical resistance of a wire filament increases with an increase of temperature; the increase of temperature results from combustion of the flammable gas on the surface of the filament, which is heated by an electric current. The filament is connected with fixed and variable resistances in an electric circuit known as a Wheatstone bridge. Any change in the resistance of the filament unbalances the bridge circuit and causes the current to flow through a meter; the movement of the meter's pointer over a graduated scale indicates directly the percentage of combustible gas (methane) in the air.

CARBON MONOXIDE DETECTORS

Because of the harmful effects of carbon monoxide on the health of persons breathing it, suitable methods for its detection in gases produced by mine fires and explosions are necessary so that the potential hazard may be determined quickly and proper measures taken to safeguard men engaged in extinguishing and sealing the fire and in recovery operations. During known or suspected mine fires and after sealing mine fires the accurate determination of low percentages of carbon monoxide is of utmost importance. Many incipient mine fires could be prevented from reaching serious proportions if an efficient method of detecting low concentrations of carbon monoxide were employed. Carbon monoxide, even in very low concentrations, behind fire seals is a strong indication that the fire is still burning or at least has been burning too recently for the area to be opened with safety.

The field methods or devices used for detecting carbon monoxide in mine air are:

1. Iodine pentoxide (hoolamite) detector.
2. National Bureau of Standards colorimetric detector.
3. Canaries or other small animals.
4. Pyrotannic acid method.
5. Carbon monoxide indicators (hopcalite catalyst).
6. Analysis of air samples (portable Orsat).

Iodine pentoxide (hoolamite) detector.—The hoolamite detector has replaced, to a large extent, the use of canaries and small animals. Hoolamite is a mixture of iodine pentoxide and fuming sulfuric acid on granular pumice stone. In contact with carbon monoxide iodine is liberated, changing the originally white granules to bluish green of increasing depths, violet, brown, or black, depending upon the concentration of carbon monoxide. Air is drawn into the detector by squeezing an aspirator bulb and passes through a tube containing hoolamite. The resulting color, if any, determines the concentration of carbon monoxide present. The comparison scale is devised for a range of 0.10 to 1.0 percent of carbon monoxide by making a test with 10 squeezes; however, if readings are made after 20 squeezes or 5 squeezes and corrections are made in the percentage indicated on the scale, the range may be extended from 0.05 to 2.00 percent (fig. 28).

National Bureau of Standards colorimetric method.—The Bureau of Standards colorimetric detector,[63] developed during World War II for use in and around aircraft and other military equipment and installations, permits the estimation of concentrations of carbon monoxide of 0.001 to 0.1 percent by volume in a few minutes. This detector, shown in figures 29 and 30, is used in some mines for the quick determination of low concentrations of carbon monoxide.

Canaries or other small animals.—Small birds and animals, especially canaries and mice, have long been recognized as a means of detecting carbon monoxide; however, small animals or birds are not safe indicators of oxygen-deficient atmosphere because some small animals will live in an atmosphere whose oxygen content would kill human beings. Moreover, some animals are markedly more resistant to carbon monoxide than others; tests show also that there is wide variation in the susceptibility of individual canaries to carbon monoxide, and undue dependence cannot be placed on an individual bird unless its characteristics are known from previous tests in known concentrations of carbon monoxide gas.

Pyrotannic acid method.—The pyrotannic acid method was developed to determine quantitatively and accurately low percentages of carbon monoxide in the blood. The basis of this method is that a light brownish-gray suspension is formed in a few minutes when normal blood, diluted with water, is treated with a solution of pyrogallic and

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[63] Shepherd, Martin, Rapid Determination of Small Amounts of Carbon Monoxide: Anal. Chem., vol. 19, 1947, pp. 77–81.

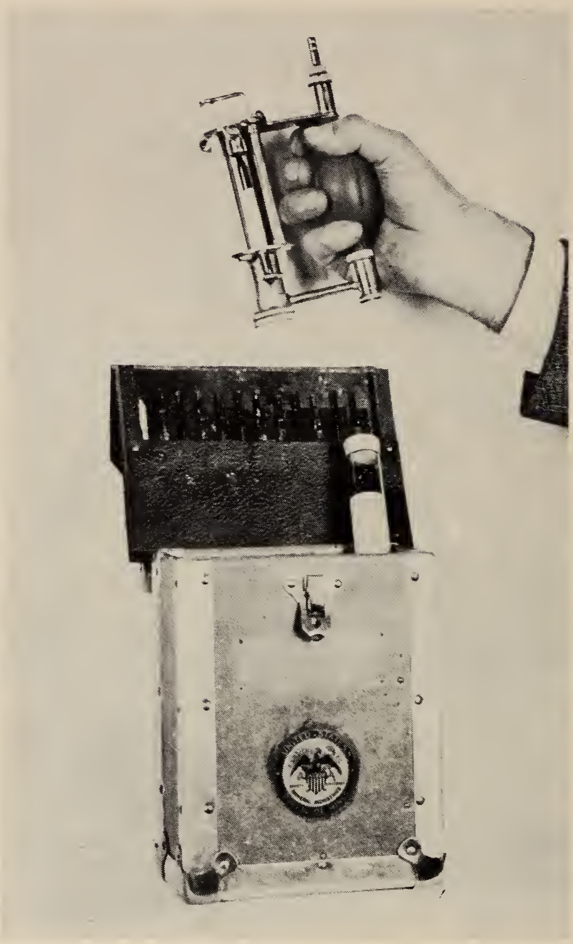

FIGURE 28.—Iodine Pentoxide (Hoolamite) Carbon Monoxide Detector.

tannic acids, whereas light carmine suspensions are formed in blood having carbon monoxide in combination with the hemoglobin (red coloring matter). When compared with color standards of known concentration, the intensity of the carmine suspension gives the saturation of the hemoglobin in the blood being tested. The range of the method is 0.01 to 0.20 percent carbon monoxide. Permanent standards prepared from pigments are supplied with the apparatus, as those made from blood deteriorate in time and would result in inaccurate determinations. The pyrotannic acid method is adaptable for determination of carbon monoxide in both blood and air by a slight difference in procedure (fig. 31).

Carbon monoxide indicators.—A portable carbon monoxide indicator has been developed by which percentages of the gas may be read directly on a calibrated meter. The detectors are made in both hand-

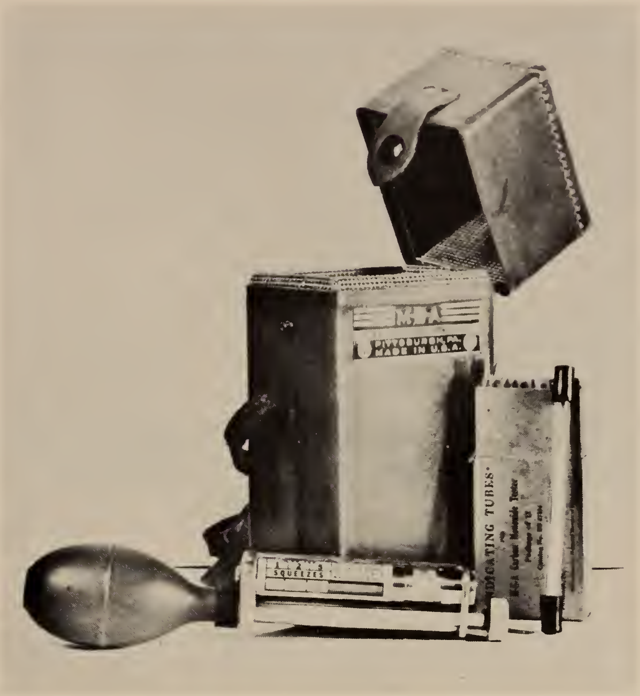

FIGURE 29.—MSA Colorimetric Carbon Monoxide Detector.

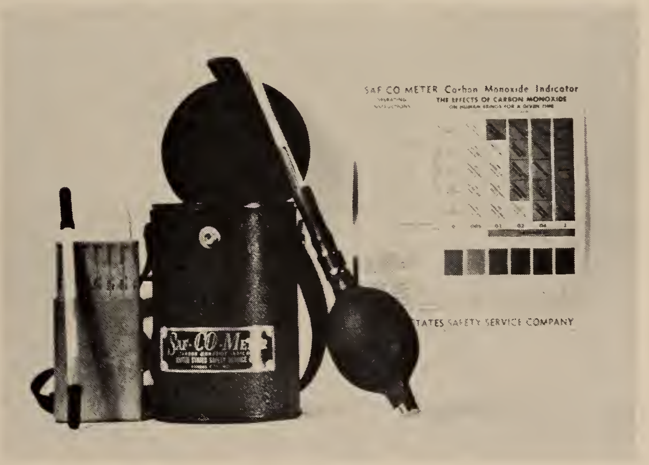
SAF CO METER Carbon Monoxide Indicator
THE EFFECTS OF CARBON MONOXIDE
TATES SAFETY SERVICE COMPANY
Saf-CO-Me

FIGURE 30.—Saf-CO-Meter Colorimetric Carbon Monoxide Detector.

operated and motor-driven types, the latter using 6-volt current from storage batteries or power circuits. The range of the hand-operated type is 0.01 to 0.15 percent; the motor-driven type may have 2 scales, one ranging from 0.00 to 0.01 percent and the other from 0.00 to 0.10

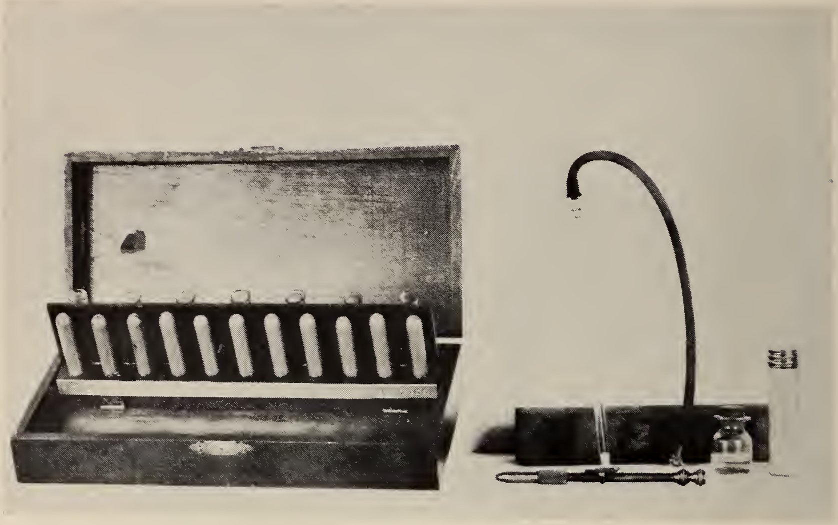

FIGURE 31.—Pyrotannic Acid Apparatus for Sampling and Determining Carbon Monoxide.

percent.[64] The air sample is drawn through the apparatus by a small pump and passes at a constant rate through a drying canister and then through a catalyst cell. The catalyst—hopcalite—is a specially prepared mixture of manganese dioxide and copper oxide which causes the carbon monoxide and oxygen to combine chemically. The reaction is accompanied by liberation of heat, the quantity liberated depending upon the concentration of carbon monoxide. The heat produced is measured by thermocouples and registered on a meter calibrated directly in percentages of CO. The continuous carbon monoxide recorder is a nonportable apparatus developed by the Bureau of Mines. It operates on the same principle as the portable types and is used for determining and recording the CO content of the atmospheres in vehicular tunnels, industrial plants, and other places where there is danger of contamination. Recording indicators of this type have been installed on compressed-air lines at several mines in the Lake Superior district and perhaps at some other mines to avoid excessive carbon monoxide content in the mine air lines due to excessive oil and heat or other contributing causes. When the carbon monoxide present exceeds the set limit, power to the compressor is automatically cut off The sensitivity of the carbon monoxide recorder may be varied to suit the conditions under which it is to be used. A sensitivity to 0.0001 percent of carbon monoxide in air is said to be obtainable. The recorder is adapted to the determination of relatively low concentrations of carbon monoxide in air; however, relatively high concentrations may be determined by diluting the sample with air and applying a suitable correction to the recorded concentration.

Analysis of air samples (*portable Orsat*).—Carbon monoxide in mine air can be determined accurately by collecting and analyzing an air sample in one of several types of volumetric gas-analysis apparatus. This is done by taking a measured amount of an air sample, absorbing the carbon monoxide in a chemical, and measuring the resulting contraction of the sample. It may also be determined by combustion in a copper oxide tube heated to 300° C. The carbon monoxide is oxidized to carbon dioxide, which is absorbed in an alkaline solution and the contraction measured.

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[64] Berger, L. B., and Schrenk, H. H., Methods for the Detection and Determination of Carbon Monoxide: Bureau of Mines Tech. Paper 582, 1938, p. 16.

DETERMINATION OF ALDEHYDES

Aldehydes may be detected by their characteristic odor, but for determination of percentages of the gases samples must be collected in specially prepared vacuum bottles. These vacuum bottles[65] have a capacity of 500 ml. and contain 25 ml. of a 1-percent aqueous solution of aldehyde-free methyl alcohol. The bottle is evacuated to the vapor pressure of the liquid and sealed. The sample is collected by breaking the sealed cap at a file mark and resealing. Temperature and barometric pressure existing at the sampling location should be noted.

The impinger method has been used to a limited extent in sampling the general atmosphere of mines where diesel equipment is used and, though rather tedious, has proved satisfactory for determining low concentrations of aldehydes.

DETERMINATION OF OXIDES OF NITROGEN

Oxides of nitrogen may be detected by the characteristic "burned powder" odor or by its reddish color in high concentrations. For detection of low concentrations and determination of percentages of oxides of nitrogen, samples must be collected in specially prepared vacuum sampling bottles. These bottles contain 10 ml. of dilute sulfuric acid plus a few drops of hydrogen peroxide. The samples are taken by breaking the glass tip from the bottle and resealing with a rubber cap. The sample is analyzed in a laboratory such as the gas-analysis laboratory of the Bureau of Mines at Pittsburgh.

In the State of Washington a portable instrument (Mine Safety Appliances Co.) is used by the metal-mine inspector in several mines where diesel-powered equipment is used underground. Assuming that the maximum allowable concentration for oxides of nitrogen in the air breathed by workmen is 25 p. p. m., it is reported that the instrument is accurate to the extent that the user can tell when the air contains 25 p. p. m. or more of oxides of nitrogen.

DETERMINATION OF CARBON DIOXIDE

Determination of carbon dioxide and low concentrations of oxygen in air may be made by analyzing samples on a gas-analysis apparatus such as the Orsat discussed under that heading (p. 81). Extinction of the flame of an oil-fed lamp or a candle or of a flame safety lamp will, of course, indicate low oxygen.

There are other commercial portable instruments for the quick determination of oxygen and carbon dioxide. The oxygen and carbon dioxide "Fyrite" analyzers have been used successfully for a number

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[65] Busch, H. W., and Berger, L. B., Sampling and Determination of Aldehydes in Diesel-Engine Exhaust Gas and in Mine Air: Bureau of Mines Rept. of Investigations 4531, 1949, pp. 8–9.

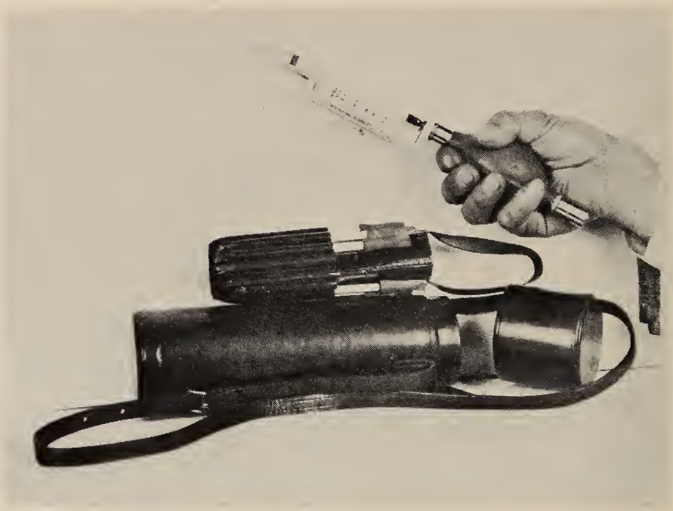

FIGURE 32.—Hydrogen Sulfide Detector.

of years for determining oxygen and carbon dioxide in the atmosphere of sealed mine fires. The results usually check within 0.3 to 0.4 percent of analysis, which is sufficiently accurate for practical purposes if the seals are tight and the progress of the work is satisfactory.

HYDROGEN SULFIDE DETECTORS

Hydrogen sulfide is detected at very low concentrations by the odor of rotten eggs, but this test will not protect against dangerous exposure, since the sense of smell is lost in 2 to 5 minutes of exposure to 0.010 to 0.015 percent of the gas. A chemical detector has been devised which indicates the existence of hydrogen sulfide in the range of 0.0025 to 0.05 percent; it is based on the reaction of silver cyanide with hydrogen sulfide, which turns white granules dark gray [66] (fig. 32).

AIR TESTING AND SAMPLING

Accurate knowledge of the quality of mine air can be gained best through samples taken underground and analyzed in a laboratory. Test for the individual constituents or contaminating gases may be made by the flame safety lamp, detectors, and indicators described in the preceding section of this circular.

A sample can be taken by filling a bottle with water and emptying it at the place where the sample is desired; the air rushes in to displace the water. The bottle is then sealed tightly and sent to the laboratory. For greater convenience, a metal or glass container with two stopcocks may be used. The water-displacement method involves small inaccuracies due to the solubility of some gases in water; samples of dry gas can be obtained by simply aspirating air through a bulb aspirator into a bottle, continuing the aspirating long enough to displace all of the original air in the bottle. The Federal Bureau of Mines uses glass bulbs that have been evacuated of air by a pump and sealed at the tip in a gas flame. By taking a vacuum tube into the place where a sample of the air is desired and breaking the tip of the tube, the air fills the vacuum and the small aperture is sealed with wax. To sample behind a mine seal, a pipe or tube is inserted through a pipe built into the seal or through some other opening in the seals and connected by hose to the sample container so the gas may flow or be aspirated into the sample container; precautions must be taken to obtain a true or representative sample. A device has been perfected by the Bureau for taking samples in deep shafts or boreholes. A vacuum tube is placed in a metal shell fitted with electrically operated attachments for breaking off the tip and sealing the tube. The shell is lowered or pushed to the sampling point and there operated by electric circuit through the three-wire cable to which it is attached.

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[66] Forbes, E. J., and Grove, G. W. (revised March 1954 by McElroy, G. E., Watson, H. A., Coggeshall, E. J., Dornenburg, D. D., and Berger, L. B.), Mine Gases and Methods for Detecting Them: Bureau of Mines Miners' Circ. 33, 1954, p. 74.

ORSAT APPARATUS

The Orsat is a gas-analysis apparatus for determining percentages of carbon dioxide, oxygen, carbon monoxide, and methane in air samples.[67] Briefly, a known volume of the gases to be tested is run through potassium or sodium hydroxide solution, which absorbs the carbon

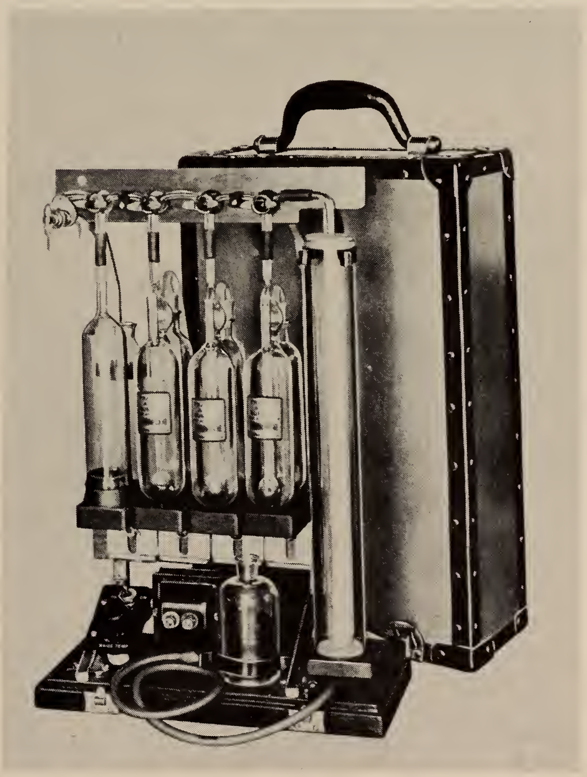

FIGURE 33.—Portable Orsat Apparatus for Gas Analysis.

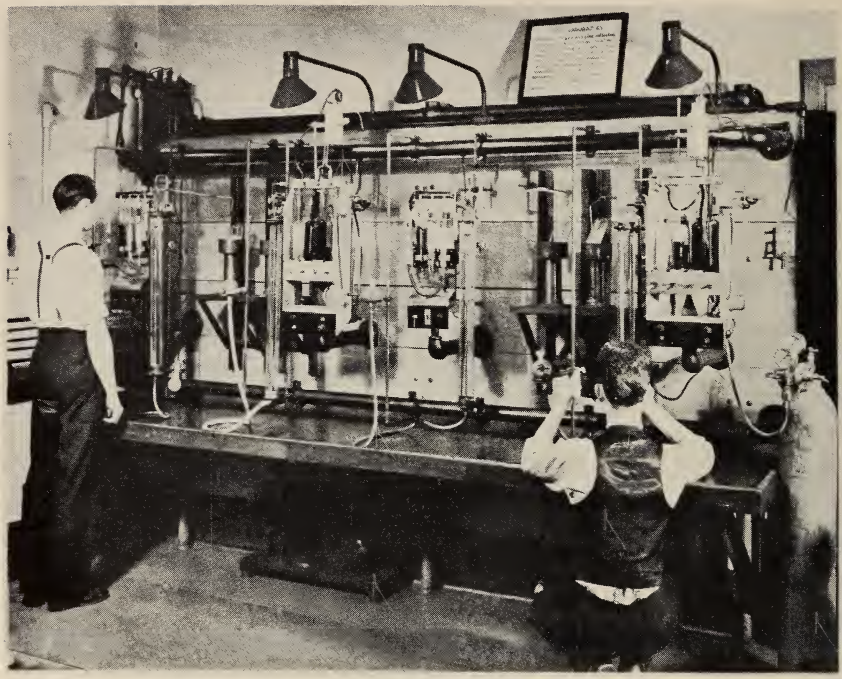

Figure 34.—Gas-Analysis Laboratory, Bureau of Mines, Pittsburgh, Pa.

dioxide in the sample. From the difference in the resulting volume of the gases the percentage of carbon dioxide can be calculated. Similarly, the oxygen and carbon monoxide contents of the gases are measured by passing the gas sample through pyrogallic acid solution and then through cuprous chloride solution. The combustible gases, such as methane, are determined by igniting the gases with an electrically heated platinum filament and calculating the percentage of methane from the change in volume. The field-type Orsat apparatus is accurate ordinarily within about 0.2 percent (fig. 33); for more precise results special laboratory apparatus is necessary (fig. 34). The manipulation of an Orsat apparatus can usually be learned after a few hours' practice.

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[67] Berger, L. B., and Schrenk, H. H., Sampling and Analysis of Mine Atmospheres: Bureau of Mines Miners' Circ. 34, rev. 1948, 103 pp.

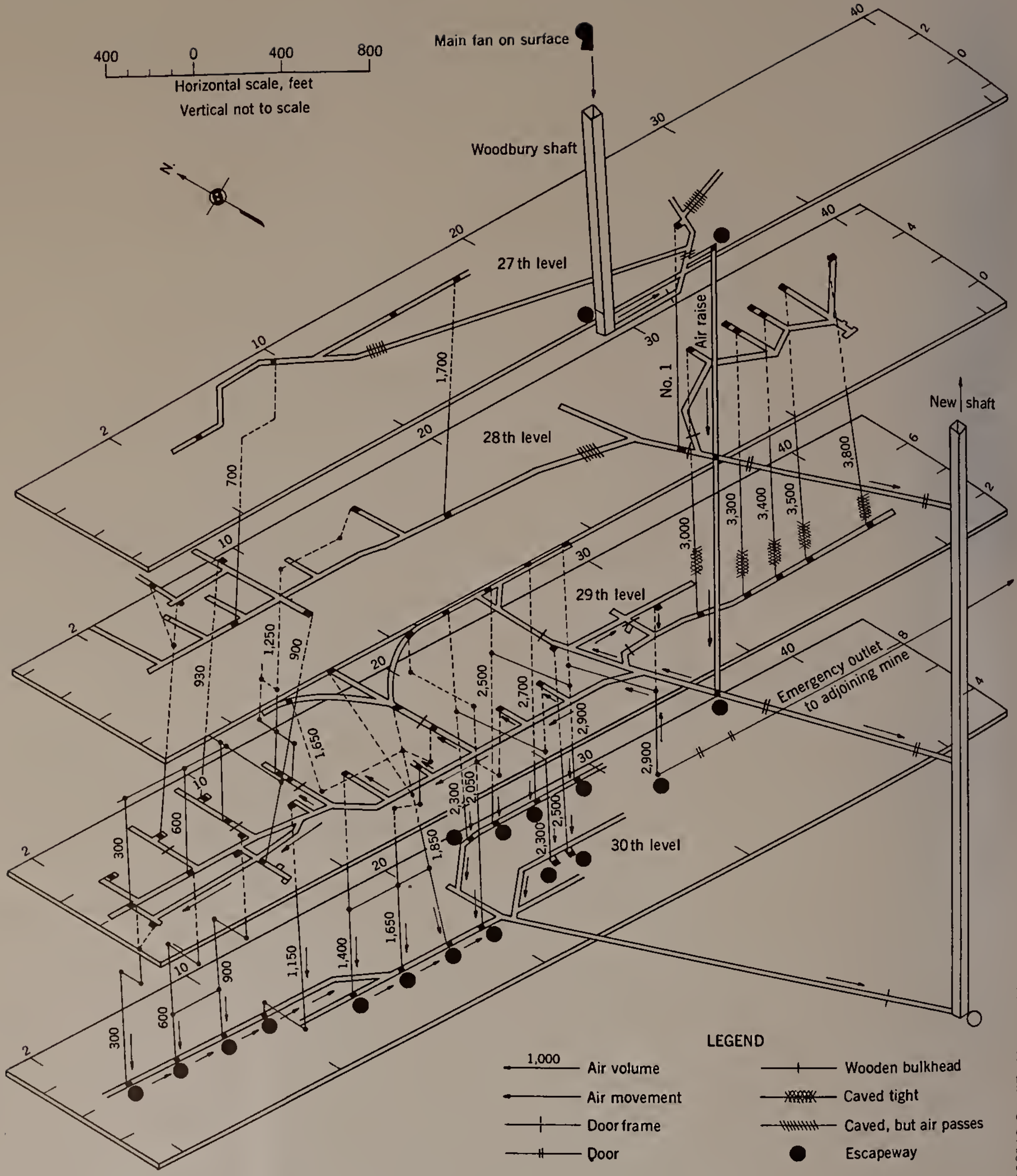

FIGURE 35.—Ventilation Map, Iron-Ore Mine in Michigan.

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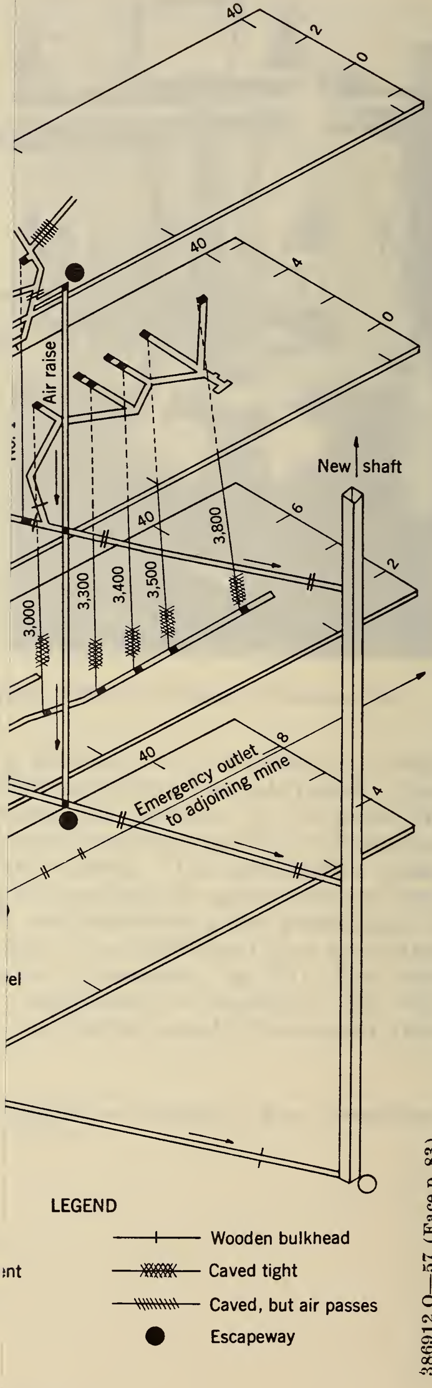

Michigan.

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MINE VENTILATION

Dependable, adequate ventilation is necessary in metal and nonmetallic mines to protect miners from dangerous gases and to provide comfortable air conditions so that they can do efficient work. When a mine fire occurs, controlled ventilation may be important to save the lives of men underground and to check the spread of the fire.

Second only to dependable, adequate ventilation is a current ventilation mine map. Figure 35 is a 3-dimensional ventilation map of an iron-ore mine in Michigan.

Because mathematical methods of analyzing alternative procedures for improving ventilation systems are so tedious as to be impracticable for many mines, the Bureau of Mines has recently installed an electrical analog computer with which such analyses can be rapidly and accurately made.[68]

The analog is a nonlinear low-voltage type especially designed for airflow problems. It has 1 main source, 4 auxiliary booster sources, 128 non-linear-resistance or free-flow circuits, and 48 linear-resistance or regulated-flow circuits. Eight of the latter have semiautomatic control for representing major intakes and exhausts.

The instrument consists of three 42- by 96-inch panels mechanically and electrically interconnected with the various elements flush-mounted on the front of the panels and interconnected at the rear. Provisions for interconnecting circuits, as required for mine-airway networks, are provided on a front network panel and by a separate "patch" or connection panel on the rear of the center panel.

Mine-airway resistances are represented to scale by calibrated tungsten-filament lamps, which have approximately the same relationship of pressure to flow as mine airways. By means of special slip-on scales, current flows are read directly on a master ammeter in terms of cubic feet per minute of airflow and voltage differences directly on a master voltmeter in terms of inches of water-pressure drop.

VENTILATION MEASUREMENTS[69]

Accurate knowledge of ventilation conditions in any mine requires a systematic survey involving actual physical measurements. Casual observations and preconceived ideas of direction and quantity of air movement, temperatures, and humidity in a mine are generally found to be erroneous when actual conditions are revealed by such a survey. These surveys involve simple measurements, made with instruments whose proper use is not difficult to learn. The important requirement is that the survey be complete enough to disclose the essential facts.

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[68] McElroy, G. E., A Network Analyzer for Solving Mine-Ventilation-Distribution Problems: Bureau of Mines Inf. Circ. 7704, 1954, 13 pp.

[69] McElroy, G. E., Engineering Factors in the Ventilation of Metal Mines: Bureau of Mines Bull. 385, 1935, pp. 2–34.

MEASUREMENTS OF AIRFLOW

For determining the direction and velocity of air currents flowing at less than 150 f. p. m., smoke clouds are most readily used. A convenient device for generating smoke clouds was developed by engineers of the Federal Bureau of Mines. A rubber aspirating bulb attached to a glass tube forces air through pumice stone saturated with titanium tetrachloride, producing a dense white cloud, which travels with the air currents. The speed with which this "smoke" travels a measured distance can be timed.

For measuring velocities of 150 to about 2,000 f. p. m. low-velocity vane anemometers are practical, convenient, and relatively accurate. The vane anemometer is a small windmill geared to a counting mechanism through a small clutch, which can be engaged at will. The blades are so inclined that 1 foot of linear velocity in the passing air current will produce 1 revolution of the vane, and readings are taken for periods of a minute to obtain the velocity in feet per minute. The cross-sectional area of the airway, in square feet, is calculated from measurements taken by using an ordinary tape or similar device, and the volume of air in cubic feet per minute is found by multiplying the area by the velocity. In taking the reading at a point in an airway the anemometer should be moved slowly and systematically over the area, as the velocity will vary in different parts (fig. 36).

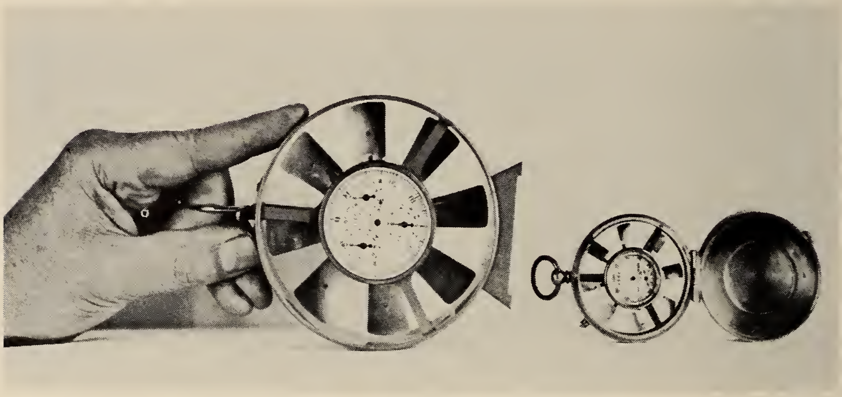

FIGURE 36.—Byram-Type Vane Anemometers.

The velometer gives satisfactory results in making detailed ventilation surveys. It is an instrument for measuring velocities of 10 to 3,000 f. p. m. by means of air-velocity pressure through calibrated orifices against a vane and spring. A series of readings can be taken in the cross section of the larger airways and averaged to give relatively accurate measurements. The velometer can also be used to read pressure by use of adaptors and is particularly useful in measuring airflow and pressure losses in ventilation tubings and ducts.

TEMPERATURE AND HUMIDITY MEASUREMENTS

Wet- and dry-bulb mine-air temperatures are conveniently obtained with a sling psychrometer—an assembly of two thermometers mounted on a frame, which can be revolved by means of a handle. The mercury reservoir of the wet-bulb thermometer is covered with muslin, which is wetted before readings are taken (fig. 37).

The instrument is whirled rapidly for about a minute or until constant thermometer readings are obtained. The evaporation of the water on the muslin has a cooling effect on the mercury in the wet-bulb thermometer, and the drier the air the more the wet-bulb temperature is lowered. The percentage of saturation (relative humidity) can be determined by reference to psychrometric charts or tables for the temperatures recorded.

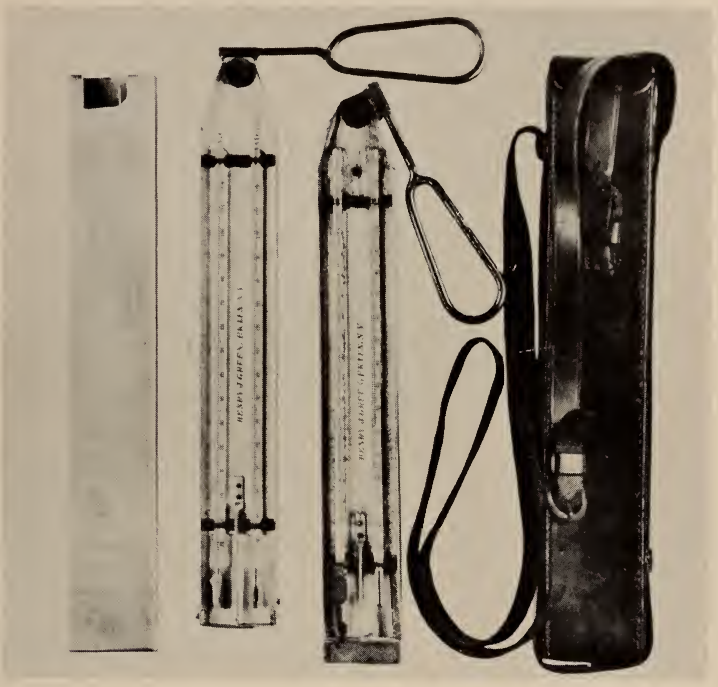

FIGURE 37.—Bureau of Mines Sling-Type Psychrometers and Carrying Cases.

PRESSURE MEASUREMENTS

Atmospheric pressures at various points underground may be read with a portable aneroid barometer if it is used carefully and with judgment; these absolute pressures are sometimes required in connection with determinations of air denisty, natural-draft factors, fan

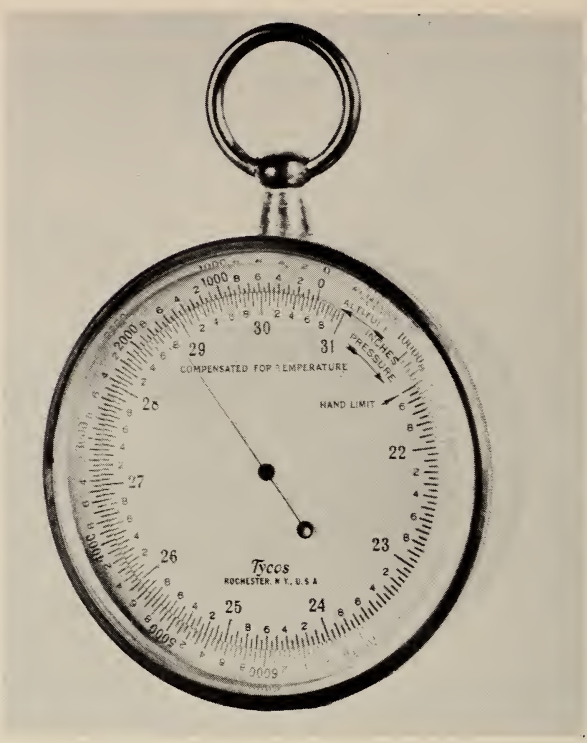

FIGURE 38.—Standard Type of Small Aneroid Barometer.

performance, air sampling, and calculations of air and gas volumes and relative humidity (fig. 38).

Differences in air pressures between the inlet and discharge of fans and the difference of pressure between the intake and the return on opposite sides of a door or stopping may be measured with a water gage. This simple device is a glass U-tube partly filled with water; with the tube in the vertical position, the difference in level of the water in the two legs is measured against a scale. In taking a reading one leg is extended by a tube through the door, wall, or stopping so that it is subjected to the air pressure on the other side (fig. 39).

A recent popular development in the U-tube for measuring air pressures is made of plastic tubing fastened to a plastic calibrated frame. When not in use, the instrument may be rolled or folded up and carried in a pocket.

NATURAL VENTILATION [70]

PRINCIPLES

Airflow in mines or tunnels is caused by pressure differences, which may be produced by natural or mechanical forces, or both. Most of

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[70] Peele, Robert (ed.), Mining Engineers' Handbook. Natural Ventilation: John Wiley & Sons, Inc., New York, 3d ed., vol. 1, sec. 14, 1948, pp. 34–39.
McElroy, G. E., Engineering Factors in the Ventilation of Metal Mines: Bureau of Mines Bull. 385, 1935, pp. 89–103.

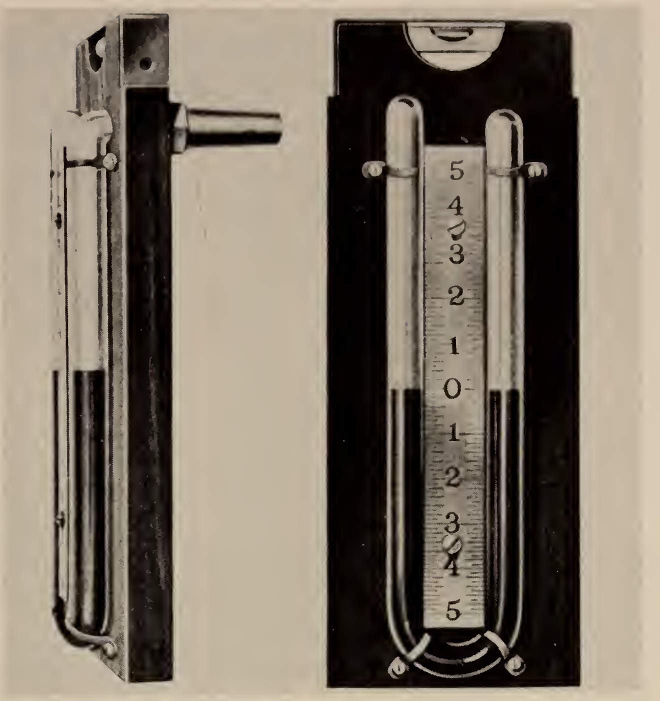

FIGURE 39.—Water Gage.

the smaller metal and nonmetallic mines in the United States and some of the larger ones depend upon natural ventilation for their main air supply, supplemented in or near working faces by compressed air and frequently by air from small blower fans. The quantity of air supplied by natural ventilation may be adequate to furnish pure air to the miners and dilute the gases from explosives, but should a mine fire occur workmen and rescue men may be imperiled by change of direction and lack of control of the air current.

Flow of air by natural ventilation is due chiefly to unequal weights of air columns in or near the mine openings; and these unequal weights are, in turn, caused largely by temperature differences. Of two connected air columns, the warmer one is likely to be lighter in weight, and therefore the air rises or upcasts; the air in the colder column sinks. Barometric pressure is essentially the total weight of an air column extending upward from the point of measurement as far as the atmosphere extends.

SHALLOW MINES

In shallow mines (working less than 1,000 to 2,000 feet in vertical depth) and in tunnels having 2 or more openings to the surface the direction of underground air movement may be seriously affected by surface winds or by movement of skips or cages in shafts or slopes or by movement of mine cars or locomotives in tunnels. Dripping or falling water in shafts may have a vital influence on direction of airflow in some mines; moreover, the surface air temperature of the air columns at and in the vicinity of the mine or tunnel openings may affect the flow of mine air. For example, if a tunnel under a mountain connects a narrow canyon at one portal and a wide valley at the other, the sun probably has access to the canyon for only a few hours a day, and the air mass at and in the vicinity of the canyon opening is cooler than the air at the opening to the wide valley. Hence, during most of the day the air is likely to intake at the canyon portal and come out the valley portal, and the differences in temperature may be sufficient to cause a large airflow; however, when sunlight or lack of sunlight equalizes the temperatures, the air may cease to flow. If the temperatures over the valley portal become lower than those over the canyon portal, the direction of flow may reverse.

DEEP MINES

In deep mines (more than 1,000 to 2,000 feet in vertical depth) the direction of main airflow remains relatively constant, irrespective of surface changes in temperature, although the quantity of air in circulation will be affected. However, mine-air temperature ultimately reaches essentially the temperature of the underground rock or dripping water. When surface air temperatures are materially higher than the underground rock or water, mine air tends to flow in one direction; then when surface air temperatures fall materially lower than the underground rock or water, the direction of flow of underground air reverses. When underground rock and water temperatures are approximately the same as surface air temperatures, there is likely to be little or no flow of air in naturally ventilated mines.

Barometric changes due to change of weather make relatively little difference in natural draft. Also, differences in barometric pressure due to differences in elevation between two portals have relatively little influence on circulation of air.

If a mine is ventilated mechanically, the natural pressure differences proportionately affect the quantity and direction of airflow and will enhance or lessen the air circulated normally by the mine fan, depending upon whether the mechanical and natural forces are acting in conjunction with or in opposition to one another.

Currents started artificially in deep mines, when the mine atmosphere is in equilibrium, may determine the more or less permanent direction of flow owing to temperature changes caused by the flow. In deep, naturally ventilated mines, operating shafts are likely to be upcast, because a slight excess production of heat in them due to hoisting of rock and ore from bottom levels and the use of machinery, electric lights, etc., in shaft stations giving off heat starts a feeble upcast current which, in turn, may increase temperature differences and also increase flow.

Air, water, and steam jets often are employed to provide circulation of air and may be used under certain circumstances to control natural-draft circulation; in some mines the flame of candles or carbide lamps is used to induce airflow locally. They act naturally by changing air temperatures and thus promote natural drafts; they also act mechanically in that the mechanically produced velocity of discharge is equivalent to generation of pressure. Thus, cool falling water in a shaft can lower the temperature of the air and set up or increase a downdraft; of greater importance, the velocity of the fall has an injector effect, causing air to flow into the lower parts of the shaft and thence to the mine workings.

Where natural or mechanical circulation is slight or absent and the air columns producing airflow are relatively short, a simple way of starting or increasing the circulation of air is to increase the length of the acting columns by an actual increase in length of one of the pair, as by adding a stack or chimney to the return-air shaft. Their efficiency depends on the relative increase in length of the acting columns; in deep mines their affect is negligible.

Winds generally have little or no effect on flow of mine air except in shallow mines and tunnels. In some instances, winds denote a lack of equality of absolute pressures on the surface and often are given full credit for ventilation of tunnels through hills on which their effect is really negligible. Such tunnel ventilation may be due in many instances to differences in weights of surface air columns of equal vertical height at the respective portals, which may be measured by the difference in barometric pressures at the two portals, corrected for difference in elevation.

Even natural ventilation in a mine is subject to a considerable degree of control through changes in openings, airways, and the opening or closing of underground connections. Poor ventilation often is accepted as a matter of course when a few simple changes in airway conditions or their grouping might effect improvements. However, natural ventilation generally is variable, inefficient, and largely uncontrollable.

MECHANICAL VENTILATION

In most large, deep mines mechanical ventilation becomes a necessity to maintain an efficient rate of operations, and in almost any underground working a fan or other device must be used to move gases and fumes from blasting to avoid prolonged waiting for the action of whatever natural ventilation there may be. Furnaces, air and steam jets, and fans are mechanical aids that have been used, air jets and fans being the common mechanical ventilating units now found in mines. Some ordinary fan types are:[71] Centrifugal fans, disk fans, and propeller fans.

TYPES OF FANS

The centrifugal fan[72] takes in air at the center of one or both sides of a fan wheel and discharges along the circumference. It is a low-pressure, large-volume air pump adapted to circulate air through mines. The direction of airflow may be reversed at surface installations by means of doors in the fan housing; flow in underground installations is reversed by doors and special arrangements of airways. Reversed flow volumes are usually (but not necessarily) somewhat less than normal. Centrifugal fans are divided into three types, according to the shape of the blades in the wheel—radial-blade, forward-curved-blade, and backward-curved-blade. Most centrifugal fans installed for primary ventilation in the metal mines of the United States are of the forward-curved-blade type.

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[71] McElroy, G. E., Engineering Factors in the Ventilation of Metal Mines: Bureau of Mines Bull. 385, 1935, pp. 104–132.

[72] Montgomery, W. J., Theory and Practice of Mine Ventilation: Jeffrey Manufacturing Co., 1st ed., 1936, pp. 235–236.

Peele, Robert (ed.), Mining Engineers' Handbook. Mechanical Ventilation: John Wiley & Sons, Inc., New York, 3d ed., vol. 1, sec. 14, 1948, pp. 39–54.

McElroy, G. E., Engineering Factors in the Ventilation of Metal Mines: Bureau of Mines Bull. 385, 1935, pp. 104–132.

Disk and propeller fans are axial-flow fans with vanes or blades attached to a shaft through a central hub. They operate at high speeds (150,000 c. f. m.) and are sometimes called the direct-expulsion group (fig. 40).

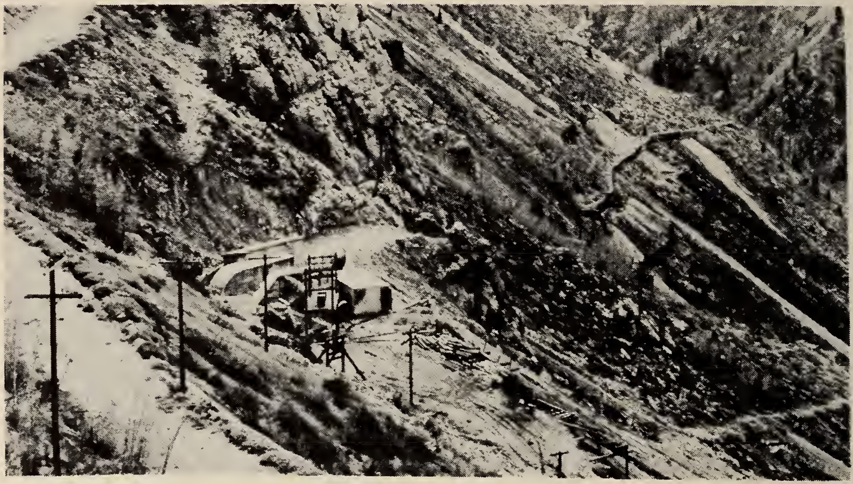

Figure 40.—Propeller-Type Fan Installed on Surface.
(Courtesy Jeffrey Mfg. Co.)

The disk fan has been used for many years and is adapted to use in small mines and those where resistance to air passage is low. Pressures rarely exceed 1.5 inches water gage. Airflow may be reversed by changing the direction of rotation of the fan, usually by switching the leads on the motor. The volume of air delivered when the direction of air circulation is reversed will depend upon the shape of the blades. If the blades are flat and straight, there will be no reduction; but with some types of blades and pitch-angle settings of blades, circulation may be reduced 30 to 70 percent by reversing.

The propeller or air-screw fan, a recent development of the disk fan, may be used to circulate large quantities of air through both small and large mines and mines having high resistance. Advantages of this type of fan are relative cheapness and easy reversal of flow, nonoverloading power characteristic (also true of the backward-curved-blade centrifugal), and high efficiency. A possible disadvantage is their noisiness. One type of propeller fan is said to deliver 77 percent of its normal volume when reversed.

LOCATION OF MAIN FANS

Main fans installed on the surface are likely to be more accessible and are subject to maximum control. A fan underground may be inaccessible during a fire or may be put out of commission by cutting off the power underground or by burning if the installation is not fireproof; moreover, in some instances underground fans, when out of working order, may be so located in mine passageways as to obstruct airflow during a fire or other emergency. Normal operating conditions may favor an underground location of the main fan where it may be more accessible in certain mines than on the surface, but provision should be made for emergency service by the installation of a surface fan, which may be used as a standby in case of a fire underground, or separate power sources should be connected to the fan and remote control provided; mine fires are so extremely costly that all the insurance possible is not likely too much (figs. 41 and 42).

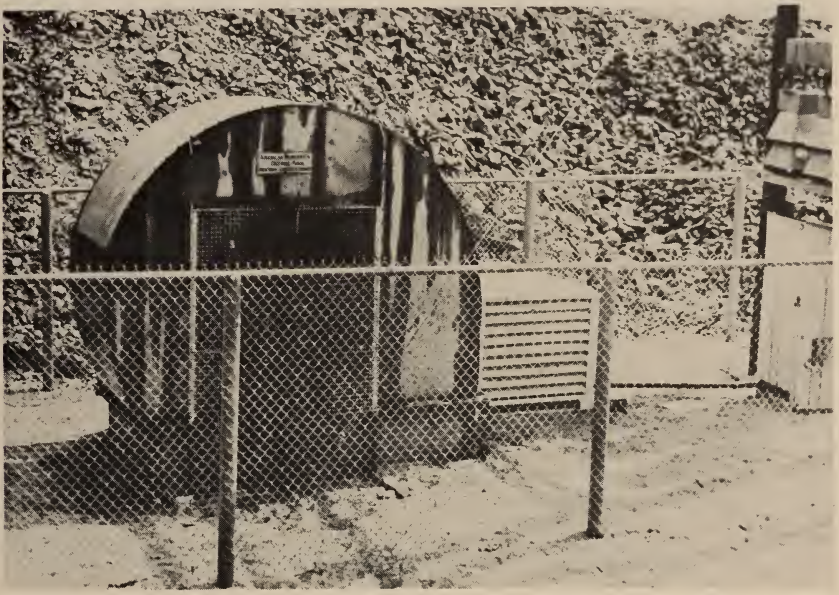

FIGURE 41.—Centrifugal-Type Fan on Surface.

Where all surface openings are required for operations, underground fan installation is usual, rather than construction of an air lock at a surface opening to allow haulage or hoisting (fig. 43).

Underground installations may require air locks on main haulage levels that otherwise might be left open and are prone to recirculation of air, a dangerous condition during a mine fire and normally undesirable.

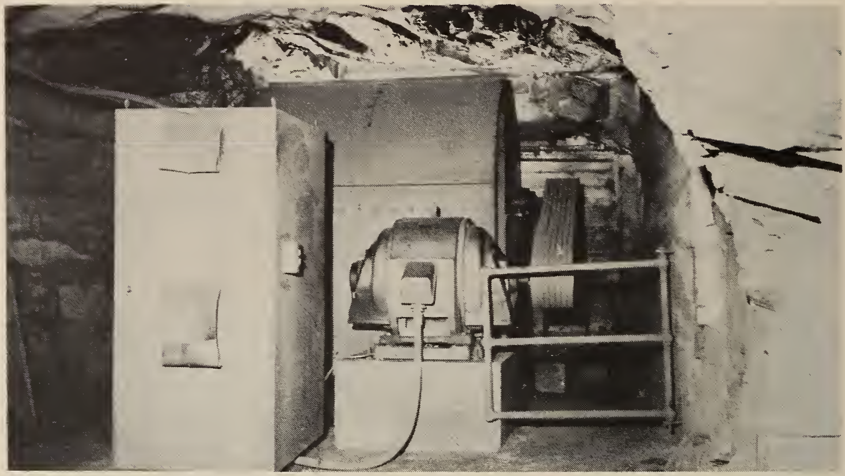

FIGURE 42.—Centrifugal-Type Fan Installed Underground.

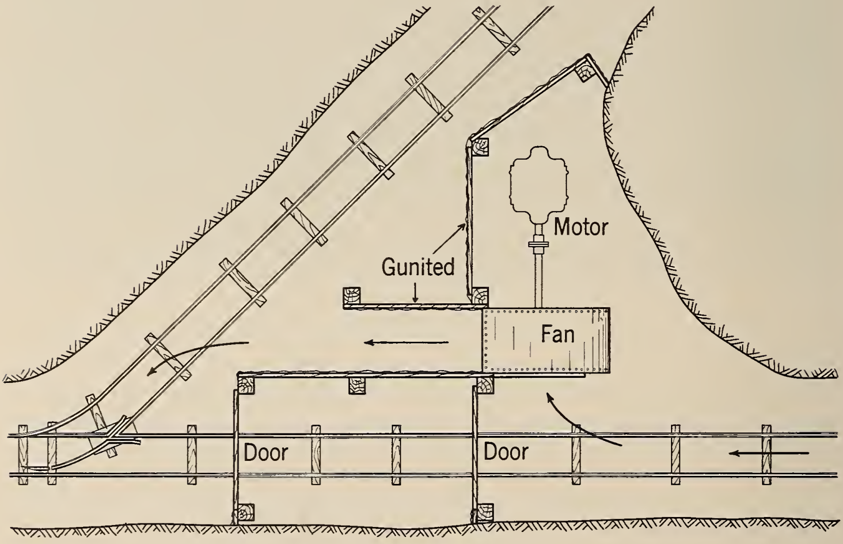

FIGURE 43.—Typical Underground Fan Installation.

The Bureau of Mines recommends:

1. That underground metal mines be equipped with a main fan in a fireproof housing, located preferably on the surface. The fan installation should be designed to ventilate the mine adequately throughout and to permit prompt reversal of direction of airflow.[73]
2. That the main intake and main return air currents in mines be in separate shafts, slopes, or drifts; that the main intake shaft lining be of fireproof construction and there be a minimum amount of flammable material in or adjacent to the shaft.[74]
3. While driving tunnels or drifts and sinking or raising shafts or slopes, and also in their operation, there should be an adequate ventilating current wherever men work or travel.[75]

AUXILIARY VENTILATION

BOOSTER FANS

Booster fans are used to increase the volume and pressure of the air current in part or all of the mine workings, where the movement of air by the main fan is inadequate. Booster fans are used in this way to regulate the flow of air because the method is cheaper and more easily applied than changing the resistance of airways. In new mines where a planned and efficient ventilating system is provided these units often can be eliminated, but in older mines where the need for ventilation has outgrown the envisioned ventilating system they are often required and used. The principal disadvantage of a booster fan is that it is installed underground and may become inoperative owing to its inaccessibility in an emergency.

Figure 44 shows a rather unusual but practical use of a booster fan on a limited scale. An auxiliary fan and its 14-inch spiral-welded ventilation pipe, because of the length and size of pipe and capacity of fan, became too small as the drift advanced. To overcome this inadequacy, a centrifugal fan with a 25-hp. motor was placed in the line about midway between heading and exhaust and used as a booster fan.

AUXILIARY FANS

Auxiliary fans are those installed, usually with metal or some type of flexible tubing, to ventilate unconnected or dead-end openings and are commonly termed "blower" fans, as the fan is run blowing more often than exhausting. Where they are run exhausting, metal tubing is generally used in place of other types, and local conditions determine the choice of method. If the air contains harmful gases, an exhaust system is usually more desirable than the blowing system. In some mines exhaust and forced systems are used alternately, the exhaust to remove gases from blasting and then the blower system for comfort and dilution of dust.

Figure 45 shows an arrangement using two high-speed, high-pressure fans in series to ventilate a development heading through 16-inch ventilation pipe in a Michigan iron-ore mine. The unit can be reversed and used to exhaust the smoke and gases after blasting by the manipulation of two sets of tandem valves. When the unit is used

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[73] Mine Safety Board, Main Fan Installations at Metal Mines: Bureau of Mines Inf. Circ. 7078, 1939, 2 pp.

[74] Mine Safety Board, Recommendations of the United States Bureau of Mines on Certain Questions of Safety as of October 1936: Bureau of Mines Inf. Circ. 6946, 1937, pp. 13–14.

[75] Work cited in footnote 73, p. 29.

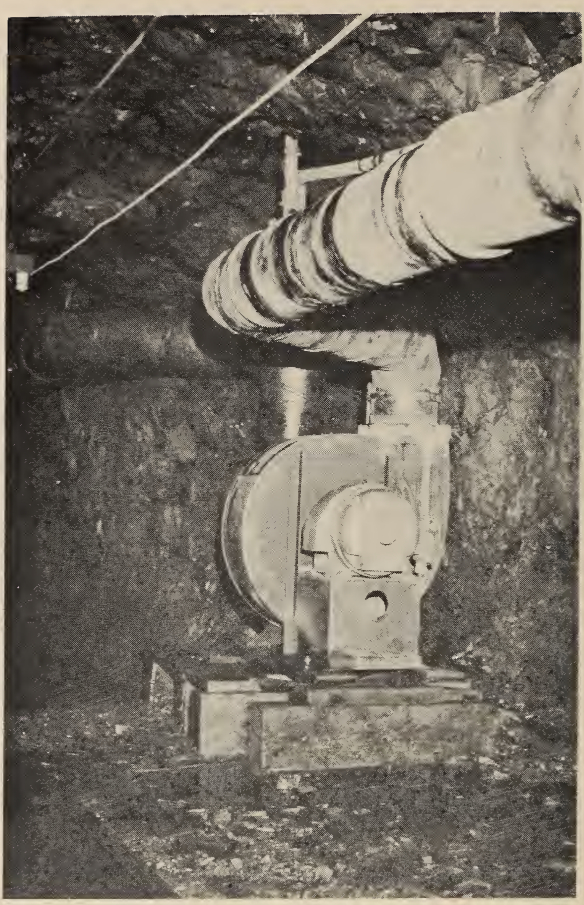

FIGURE 44.—Booster Fan Installed in a 14-Inch Metal Air Line.

blowing, air enters from the right pipe, flows down the inclined section and thence through the two fans, and is thus forced up to the tee in the center and through the left pipe to the breast. To use the unit exhausting, the operation of the valve is reversed.

The following information has been abstracted from a paper [76] presented at the December 9, 1953, monthly meeting of the Lake Superior Mines Safety Council, Ishpeming, Mich., by A. L. Beissel, Jr.[77]

> Auxiliary ventilation is a prime requisite for sinking shafts and driving drifts until the time when the main ventilation system can be placed into operation, usually when two shafts have been connected. After the air from the main ventilation system has been properly coursed and distributed, various auxiliary installations nearly always are required to take air from the main aircourses to ventilate the mining faces or to continue development.

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[76] Beissel, A. L., Jr., Auxiliary Ventilation : Surface Plants and Underground : Skillings Min. Rev., Jan. 9, 1954.

[77] Ventilation engineer, Gogebic district, Pickands Mather & Co.

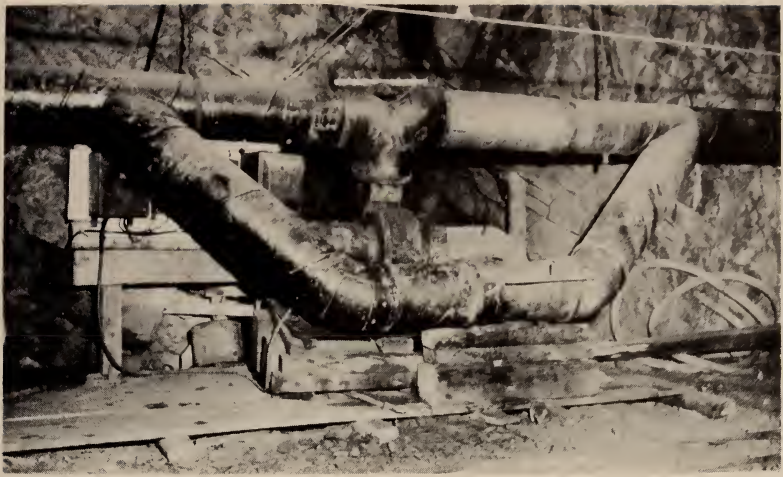

FIGURE 45.—Two-Fan Reversible Unit.

Experience has shown that volumes of 2,000 c. f. m. for an ore heading and 3,000 c. f. m. for rock drifts less than 100 square feet in area provided very good ventilation for dust control and smoke removal. A volume of 1,000 c. f. m. has been found satisfactory for ventilating double-compartment raises, each averaging 5 by 5 feet. Volumes ranging from 7,000 to 20,000 c. f. m. were maintained for shaft-sinking operations to a depth of 3,750 feet in which the shaft area was about 300 square feet.

Using these standards as a basis for good ventilation, plans are made accordingly to procure the proper sizes in fans and tubing. Charts are available with pressure-volume data for airflow in metal pipe and canvas tubing. Generally, canvas tubing requires 1½ times as much pressure for the same volume as does metal pipe.

Fan curves that depict the performance of fans for pressure, volume, horsepower, and mechanical efficiency are furnished by fan manufacturers. By plotting the system curve for pipe or tubing required for any particular heading on the fan curve, a choice can be made, based usually on the size, speed, and cost of the fan. Nearly every fan has a wide range in pressures and volumes, which allows for errors in the pipe-system curves.

In a recent shaft-sinking operation 24-inch spiral-welded metal pipe was used to exhaust 7,000 to 20,000 c. f. m. from the shaft; the end of the suction pipe was 40 to 80 feet from the bottom. As the shaft advanced from the collar, the fan output was 20,000 c. f. m., which gradually diminished as pipe was added to 7,000 c. f. m. at a depth of 3,100 feet. At this depth the 50-hp. fan delivered to the 23- by 14-foot shaft 7,000 c. f. m. at a static pressure of 9.1 inches water gage. A similar fan was connected at the collar in series; this increased the volume to 12,000 c. f. m. and the fan pressure to 20.4 inches water gage. A 15-hp. fan with 12-inch canvas tubing placed above the suction provided air to sweep the working area.

Up to 1,400 feet of drift can be driven with one 15-hp. fan, and at least a mile can be driven satisfactorily with additional fans, provided excess leakage does not develop in the line; 16-inch metal pipe and fans developing up to 13 inches water gage are used. If more than 4,000 c. f. m. exhaust is required for a heading, it is necessary to choose larger diameter pipe or higher pressure fans, or both. The controlling factor is usually the clearance between the side of the drift and mobile equipment.

Rock drifts requiring 3,000 c. f. m. at the face should have 4,000 c. f. m. or more at the suction, and the distance from the face to the suction should not exceed 80 feet. A 5-hp. fan 25 feet behind the suction, running at an average speed of 1,900 r. p. m. with 12-inch canvas tubing extended to within 30 feet of the face, is used to sweep the face. Exhaust systems are recommended for drifts that are to be driven over 500 feet in length. With an exhaust system, it is possible to clear out smoke from blasting quickly, do many jobs in the drift after the blast, and discharge the contaminated air in return aircourses or in areas not affecting other operations. Effective water sprays can be installed in the pipe to reduce dust and smoke. Fresh air must be available at the entrance of the headings driven with exhaust ventilation. Sometimes it is necessary to bring fresh air to this point with auxiliary systems. Depending on the distance, 15-hp. fans with 12- or 16-inch pipe will supply 4,000 c. f. m. of air or more.

In very wet drifts where dust-control measures, other than smoke removal, are not required the systems described often can be branched out to as many as 3 headings, each receiving a little less than 2,000 c. f. m. When blasting, 2 of the 3 branches can be closed off for smoke removal.

To maintain 2,000 c. f. m. at the faces of ore drifts averaging about 60 square feet in cross-sectional area, 5-hp. fans (1,900 r. p. m.) with 12-inch canvas tubing are used. In some places the tubing is extended as far as 300 feet. For short headings up to 100 feet 2-hp. fans and 8-inch tubing are satisfactory. If tubing must remain in a crosscut for a long time and is subjected to water or dry rotting, metal pipe will prove more economical. The 10-inch metal pipe performs as well as 12-inch canvas tubing.

Because of the difficulty in maintaining canvas tubing in raises, 8-inch metal pipe is used. Raises are seldom driven more than 150 feet, and 2-hp. fans provide adequate ventilation.

If fans and tubing are not practicable, such as in short stub drifts where repair work is done intermittently or in a remote place that cannot be reached with tubing, a compressed-air mover is sometimes used. It can be attached to a metal pipe or merely hung over the opening. Factory-made types are more efficient and make less noise than those made up in the shop.

Underground pumprooms and rectifier or converter stations are best ventilated with slow-speed, high-volume fans. Rectangular ducts are generally used, and volumes handled vary according to the amount of heat generated and the size of the room. If hooding is not practicable, more effective cooling can be obtained by blowing than by an exhaust system; however, care must be taken to prevent scaly particles from being thrown into electrical or mechanical equipment. Dust-contaminated air can be cleaned with filters.

Auxiliary systems are sometimes used to increase the flow in the main mine-ventilation system for splits that do not have enough air.

Auxiliary ventilation is used in shops and surface-plant buildings where fume, dust, moisture, and heating problems exist. Ordinary natural-draft roof ventilators are not always satisfactory because they depend largely on outside wind velocities and temperatures. Invariably, shops in which objectionable fumes are produced require power-type ventilation. It is good practice to hood and exhaust such equipment as oil burners, drill-bit sharpeners, tempering vats, and grinders rather than clear the air in the whole room. A single fan can take care of a large number of such machines where the dust- and fume-producing equipment is grouped and equipped with hoods. Welding disturbs the shop ventilation more than any other operation and should not be done without an exhauster. Locating this equipment in a separate room should be considered. Compressed-air jets as a source of power on hoods and ducts are often used to control dust and fumes from grinding wheels or other equipment.

Handling discharged air may require special attention to transport dust and fumes with sufficient velocity to prevent settlement in the pipe and to discharge the contaminated air where it will not reenter the circuit or buildings. Filters and dust separators are used where large quantities of dust are produced or where it is necessary to recirculate the air. Makeup air, tempered in the wintertime, should be provided in shops having exhaust systems.

Well-planned auxiliary ventilation systems for mines and shops are important for the control of dust and fumes, for the comfort and safety of the employee, and for efficient production.

USE OF COMPRESSED AIR

Compressed air released from a high-pressure hose is used extensively to remove fumes of explosives from faces or to ventilate hot, stagnant, blind-end workings in metal mines. A moderate volume of air, usually less than 100 c. f. m., is delivered, but the cooling effect is principally from the air motion produced, since the compressed-air temperature is seldom more than 5° below that of the air in the working place. The average cost of releasing 1,000 cubic feet of compressed air in a working place is roughly 10 times that of circulating a like amount of air by fan tubing and 40 times that for main-fan circulation. For temporary use over short periods auxiliary ventilation by compressed air may be the cheapest form available when the cost of installing better ventilating equipment and other factors are considered; the difficulty is that habits of wasteful use grow gradually in the ordinary mine as the need for additional ventilation increases with the extent and depth of the workings. Although compressed air may be employed economically to combat local and temporary discomfort due to air temperature or to unusual gas, smoke, or dust occurrence, its continuous use for such purposes generally is extremely wasteful, costly, and detrimental to the compressed-air equipment and appliances owing to the low pressures that result. The compressed air discharged from operating drills and other appliances underground increases ventilation only while the machines are in operation but adds only a fraction of the total requirements. Air motion produced by opening air lines at working faces can be provided more cheaply by injector devices that use only a small quantity of compressed air but entrain and give motion to many times this quantity of free air (fig. 46).

DISTRIBUTION OF AIR CURRENTS

Natural distribution of air currents in mine workings is nearly always inefficient and unsatisfactory; although circulation on the main openings may be good, very little air is usually circulated through the working places where it is most needed; some places receive more air than they need; others receive none. For effective and efficient distribution both direction and quantity of flow must be controlled.

One of the most important considerations in determining direction of flow is that the usual means of exit should be on intake air; this usually means that the operating opening should be an intake. In cold climates one of the chief objections to the use of operating openings as intakes is the formation of ice in the opening and the freezing of waterlines; these difficulties can be largely overcome by heating the air as it enters the opening. Return air currents may be corrosive to equipment and cause hot, foggy, smoky air conditions in a zone of great activity. On the other hand, large quantities of dust may be raised adjacent to the haulage opening that should, for safety, be used as an intake; additional expense may be necessary to prevent dust from entering the intake air. In a large mine conflicting features may be involved, and the system should be planned to satisfy as many as possible with due regard for safety and service. Where conflicts exist, safety should be given preference over other considerations. In cold climates some metal mines having several openings to the surface can hold the main haulage or hoisting opening essentially neutral to airflow but preferably slightly upcast, using a small amount of fresh air from a downcast or intake opening.

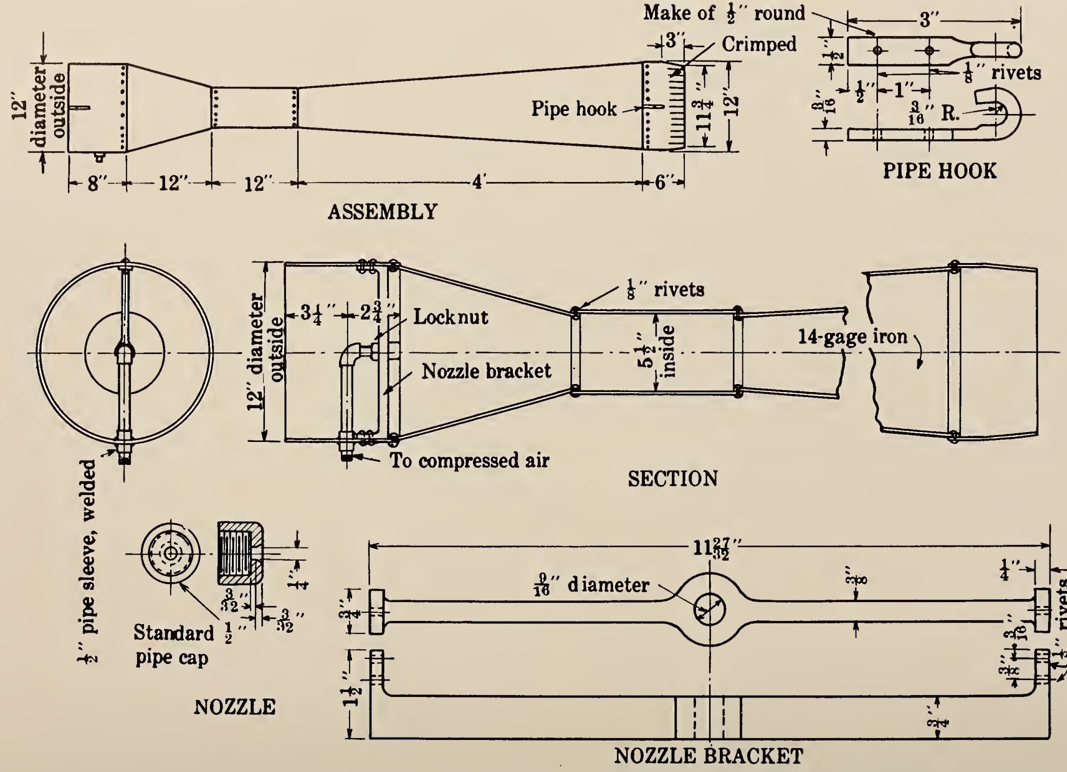

Figure 46.—Venturi-Type Compressed-Air Injector.

In large mines it is desirable to divide the workings into sections by natural or artificial barriers to force the air currents to cross from downcast to upcast through each active section of the mine and to minimize recirculation. Systematic splitting of air currents is essential to avoid having men work in overheated or vitiated currents of long air returns.

Virtually all devices used to control the distribution of air currents are included in the general term "stoppings." Tight stoppings are generally called bulkheads and may be temporary or permanent. Temporary bulkheads may be used to check air currents during a fire but usually are of too light material to withstand the concussions of heavy blasting. Permanent bulkheads are seldom used, except for sealing off fire areas. Caved or filled material is generally relied upon to prevent the flow of air through abandoned regions. Light stoppings placed in worked-out drifts or other openings to prevent short-circuiting of air in the upper levels of shaft mines are often loosely constructed so that large quantities of air are lost through them. Permanent bulkheads are readily made of concrete, masonry, brick, tile, or gunite on a wooden stopping and strengthened to resist blasting by cutting a hitch all around the drift in which the bulkhead is constructed.

Where passage for men or material is required, a door must be installed in the stopping. Doors are used extensively in metal mines for controlling the distribution of air currents; keeping ventilation doors shut is one of the most troublesome operating features of any complicated ventilation system. Under ordinary operating conditions the effects of door leakages and of leaving doors open are not always apparent, and a detailed ventilation survey is sometimes required to establish their full significance. Many types of doors are in use, ranging from single-ply doors in wooden frames to heavy iron doors set in iron frames embedded in concrete (figs. 47, 48, and 49).

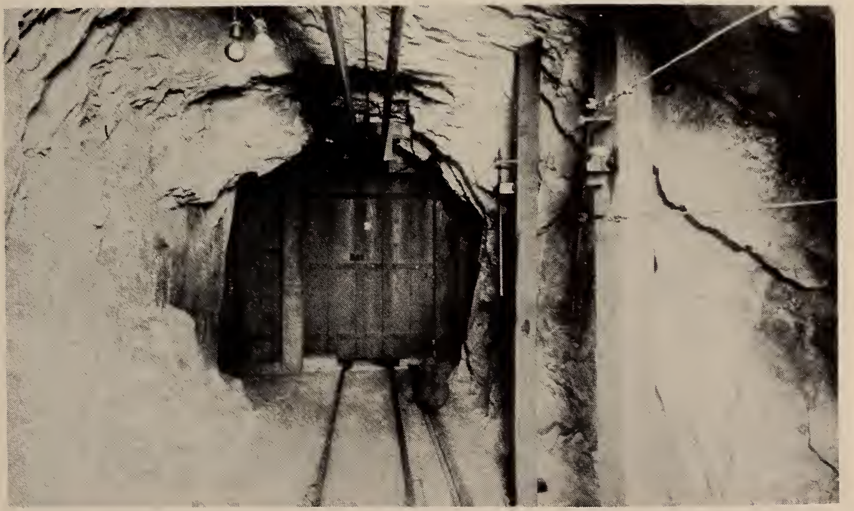

FIGURE 47.—Air-Operated Ventilation Door; Side Door for Foot Traffic.

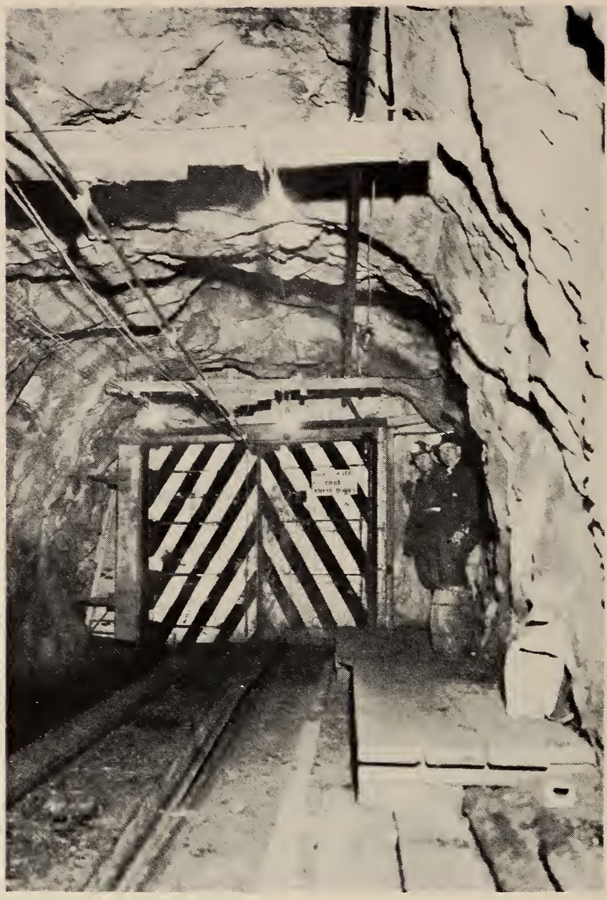

FIGURE 48.—Ventilation Door Mechanically Operated by Third Rail.

Doors should be equipped with counterweights, latches, or clamps to keep them closed under all pressure conditions. Regulator bars are sometimes provided to hold the door in a fixed position to control the volume of air passing through, or sliding panels are set in the door to serve as regulators. Doors may be eliminated in many places by installing stoppings with regulators in airways not used for haulage to split the main air current and provide each section with a proper amount. Where circulation of air at some important place must be controlled by a door, it is desirable to install a pair of doors to form an air lock, so only one door of the pair is open at a time. Double doors are most frequently used on motor haulageways, where the doors must be far enough apart to accommodate the maximum length of train. Automatic controls for opening doors are made but are used less widely than remote-controlled doors, some of which are opened by a compressed-air piston operating in a cylinder. The valve on the compressed-air line is controlled from the moving train through levers

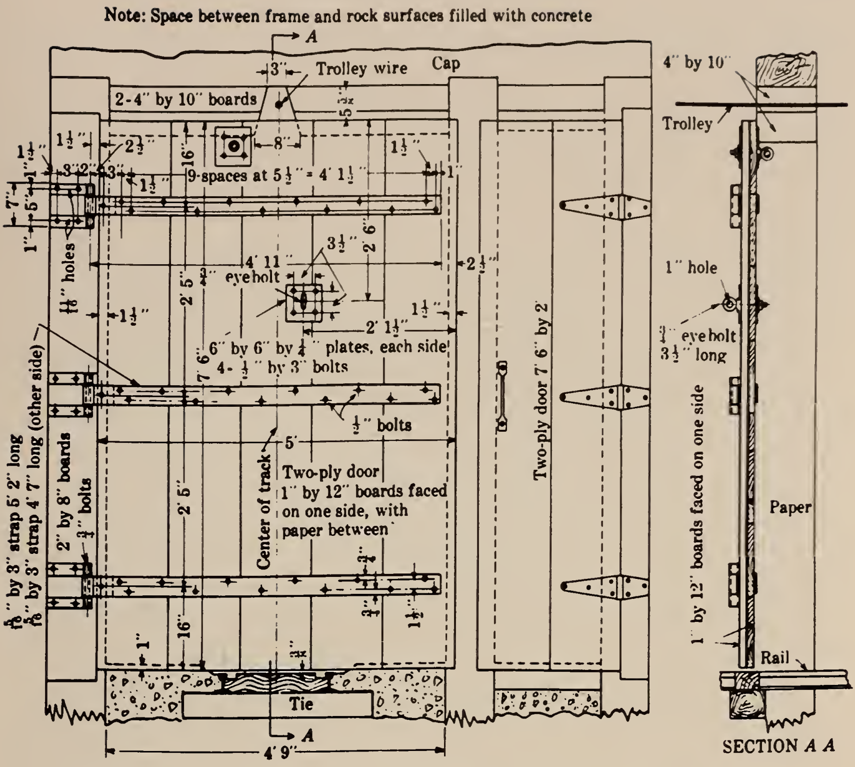

Figure 49.—Ventilation Door Used on Motor Haulage in Arizona.

attached by long wires to a single three-way valve. Doors in some mines are controlled mechanically by the weight of a car or locomotive on a third-rail leverage system.

FACTORS AFFECTING FLOW OF AIR[78]

The energy applied to moving air in a ventilation system is used chiefly in actual movement of the air and in overcoming friction and shock resistance. Friction pressure losses are caused by drag of the walls of the airways on the airstream; shock pressure losses are due to deflections and changes of cross sections in the airways, as well as obstructions such as posts and haulage equipment. Roughness of wall surfaces is the determining factor of friction losses, while the relative positions of wall surfaces largely determine shock losses. These losses of energy are very large for narrow or crooked airways as compared to those of ample cross section with gradual turns and smooth walls. Shock losses are less important than those due to friction.

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[78] McElroy, G. E., Engineering Factors in the Ventilation of Metal Mines: Bureau of Mines Bull. 385. 1935, pp. 39–89.

The shape of an airway has a relatively small influence on the frictional resistance and power requirements compared to the factors of size, smoothness, volume of air, and intrusion of obstructions. The effect of size of airways on power requirements due to friction losses is such that providing airways of ample size is a primary consideration in obtaining maximum ventilation with minimum power requirements. The ratio of power required is about 21:1 between a 4- by 6-foot and 8- by 10-foot airway for the same flow of air. Where conditions permit, the quickest and most economical method of reducing mine resistance generally is to enlarge the airways or add new ones.

The volume of air moved through an airway of a given size is also an important factor; the ratio of power required is 64:1 between flows of 25,000 and 100,000 c. f. m. As for the type of lining, a smooth-lined circular airway 4.6 feet in diameter will carry as much air as a timbered opening 5.7 feet square or a rough rock opening 6.2 feet square with the same pressure. Where the airways in a mine have high resistance factors because of timbering or irregular rock surfaces, the volume of flow can be greatly increased by smooth-lining the airways. If all the airways of a mine were changed from timber-lined to smooth-lined and the pressure remained constant or if they were rock-bolted and the pressure remained constant, the airflow would be increased about 2.2 times; a similar change confined to the main intakes and returns ordinarily would about double the flow.

Deflections from a straight line exert an influence on mine-airway resistances. Straight airways, except shafts, are the exception rather than the rule; numerous small bends and curves involving deflections of 30° or less are found in most metal-mine airways; and numerous abrupt turns are by no means unusual. Shock pressure losses increase in proportion to the degree of curvature of such bends. Variations in the area of airways have little apparent effect if the transitions are smooth and gradual; but if they are abrupt, shock pressure losses accompany the change in velocity owing to imperfect conversion of velocity pressure into static pressure and vice versa.

Obstructions and constrictions are but different forms of abrupt changes in area and may affect very short or appreciable lengths of airways. Many deviations in the airway that reduce the area, increase the rubbing surface, or change the surface conditions are also classed as obstructions. Their influence has been found by actual tests and published in terms of velocity pressure losses and increments of the friction factor. The influence of curvature, crookedness of airways, and obstructions on pressure resistance is ordinarily of secondary importance, but where irregularities and obstructions are pronounced the resistance is greatly increased, especially where velocities are high. The major types of obstructions in mine airways are cars, cages, doorframes, and other such objects, some fixed and some movable. Some types of safety gates (figs. 50 and 51) provide protection at the top of raises and yet permit the flow of air without too great resistance if the velocity is low.

In addition to the common methods of reducing mine resistance, such as increasing the area, splitting the airflow, and eliminating obstructions, consideration should be given to smooth-lining the surfaces, providing easements at sharp bends, and streamlining all necessary obstructions in main airways.

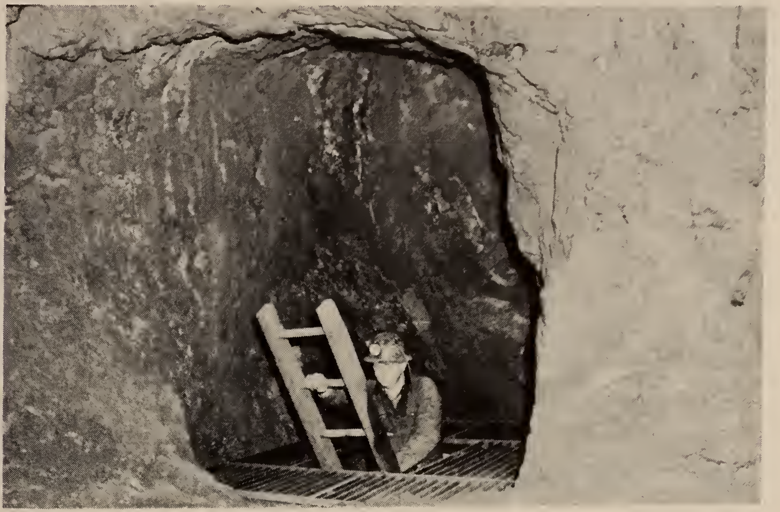

Figure 50.—Sollar and Safety Gate at Top of Raise.

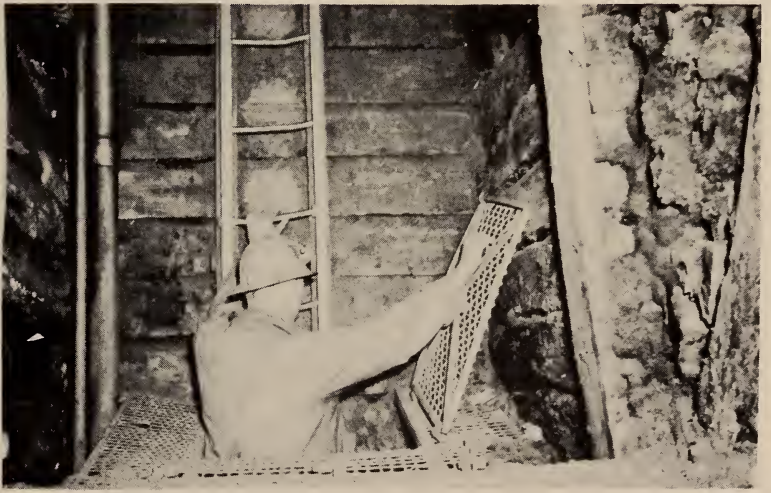

Figure 51.—Sectional Gate Over Raise at Sublevel.

VENTILATION REQUIREMENTS

QUALITY OF AIR

Pure atmospheric air contains:[79]

Gases:	*Percent by volume*
Oxygen	20.95
Nitrogen	78.09
Carbon dioxide	.03
Argon	.93

"Normal" mine air is considered to be air that is not injurious to breathe and does not contain dangerous proportions of flammable gases. The composition of normal mine air as found in representative samples does not vary greatly from that of the open atmosphere, and the quality ordinarily does not pass below that shown in the following tabulation:

Composition of normal mine air, percent

Constituent gases:	*Average, all samples*	*Most frequently found*
Nitrogen	79.19	79.16
Oxygen	20.62	20.76
Carbon dioxide	.19	.08

The first analysis given is an average of numerous samples taken and analyzed by the Bureau of Mines. These samples were taken in normal mine air in metal mines. The "average" concentrations of individual gaseous constituents as shown in the tabulation which make up the "average" analysis do not necessarily represent the mine air throughout the ordinary mine or the most probable normal mine atmosphere in the mine. The "most probable" percentages of individual gaseous constituents shown are those that occur in the greatest number of samples from representative mines. The analyses given were determined by the Bureau of Mines in a study of atmospheres in different types of underground mines.[80]

The Bureau of Mines considers mine air as unfit for men if it contains less than 19 percent oxygen, more than 1 percent carbon dioxide, or a harmful amount of poisonous gas (Mine Safety Board Decision 9) and recommends that mines be ventilated with air containing not less than 19.5 percent oxygen nor more than 0.5 percent carbon dioxide and no harmful quantities of noxious or poisonous gases. If adequate quantities of pure air are directed to the places where men work in mines, most of the requirements of health and many of the demands of safety will be served.

TEMPERATURE, HUMIDITY, AND MOVEMENT

Other factors than composition of the air have great effect on the efficiency and health of men in mines. Approximately in order of their importance, the main features that affect air in metal mines are: (1) Movement, (2) temperature, (3) relative humidity, (4) gases, and (5) dusts.[81]

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[79] Humphreys, W. J., Physics of Air: McGraw-Hill Book Co., Inc., New York, N. Y., 3d ed., 1940, p. 67.
Forbes, J. J., and Grove, G. W. (revised March 1954 by McElroy, G. E., Watson, H. A., Coggeshall, E. J., Dornenburg, D. D., and Berger, L. B.), Mine Gases and Methods for Detecting Them: Bureau of Mines Miners' Circ. 33, 1954, 82 pp.

[80] Ash, S. H., Carbon Dioxide Content of Mine-Fire Atmospheres as an Aid When Fighting Metal-Mine Fires: Bureau of Mines Inf. Circ. 7590, 1950, 25 pp.

With a dry-bulb air temperature above 75° F., comfort and maximum working efficiency can be attained only when the air is moving, especially if the relative humidity is high. In hot, humid, stagnant air men are likely to be affected by dizziness or inability to think clearly or quickly; consequently, the accident hazard is increased. Studies by the Bureau of Mines[82] revealed that between effective temperatures of 40° and 75° F. the amount of work performed is virtually constant; above 75° F. the output falls gradually until 80° F. is exceeded, when the fall becomes rapid. "Effective temperature" is a term used to mean any combination of temperature, humidity, and air movement that will give the same feeling of warmth or cold as does quiet, saturated air at that temperature. Thus, any air condition has an effective temperature of 60° when it induces a sensation of warmth like that experienced in slowly moving air at 60° saturated with moisture.

The critical temperature in still air which limits the performance of work in mines has been found to be 78° F., wet-bulb; at 80° the amount of work performed decreases; at 85° hard work is very difficult, if not impossible; and at 88° it is impractical for unacclimated persons to remain in the air and work reasonably vigorously for long periods. The wet-bulb temperature at which most men are likely to collapse in time is said to be 93° where the air is not moving.

Until the dry-bulb temperature approaches 75° F., a relative humidity close to saturation causes little discomfort, even in still air, unless the air is depleted of oxygen or is contaminated with excessive quantities of noxious gases. Normal work can be performed when such air is circulated at a velocity of 25 feet or more. Stagnant air, even if pure, is oppressive when the relative humidity is 85 percent or more and the temperature is 75° to 85° F., and its oppressiveness is greatly intensified by even a small decrease in oxygen content or increase in carbon dioxide. Hard work can be done without appreciable discomfort in pure air at these temperatures if it is circulated at a velocity of 100 f. p. m. or more. Stagnant air, regardless of purity and humidity, is oppressive at 90° to 95° F., and the oppressiveness increases as the air approaches saturation. The oppressiveness is overcome if such air is moved at a velocity of 400 f. p. m. or more. Hence, if adequate movement is supplied, the relative humidity is not a deciding factor until the temperature exceeds 100° F. and humidity approaches 100 percent. Where enough ventilation is provided to cope with the difficulties of stagnant air, humidity, and temperature, the purity of the air is easily maintained because of the much greater volume needed to cool the workings than to replace depleted oxygen or remove noxious gases.

AIR CONDITIONING

In some mining regions the ventilating air is heated to prevent freezing in shafts and on intake haulageways and to provide comfortable working conditions for men working on intake air during cold weather. In other regions the air must be cooled to reduce the rock temperatures for health and efficiency in mining.

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[81] Harrington, D., Mine Ventilation: Bureau of Mines Inf. Circ. 7047, 1939, p. 3.

[82] Harrington, D., and Davenport, S. J., Review of Literature on Conditioning Air for Advancement of Health and Safety in Mines. II. Need for Air Conditioning Indicated by Physical Quality of Underground Air: Bureau of Mines Inf. Circ. 7182, 1941, 104 pp.

In many of the Lake Superior iron-ore mines heating units are an integral part of the ventilation plant. Figure 52 shows a surface ventilation plant in Minnesota in which the air is heated as it enters the fan and is blown into the mine. Figure 53 shows heating units for mine intake air in Michigan. The approximate capacity of these units is 3,300,000 B. t. u. per hour. They are used in heating 35,000 c. f. m. of air from minus 30° to above freezing. Ten grid-type unit

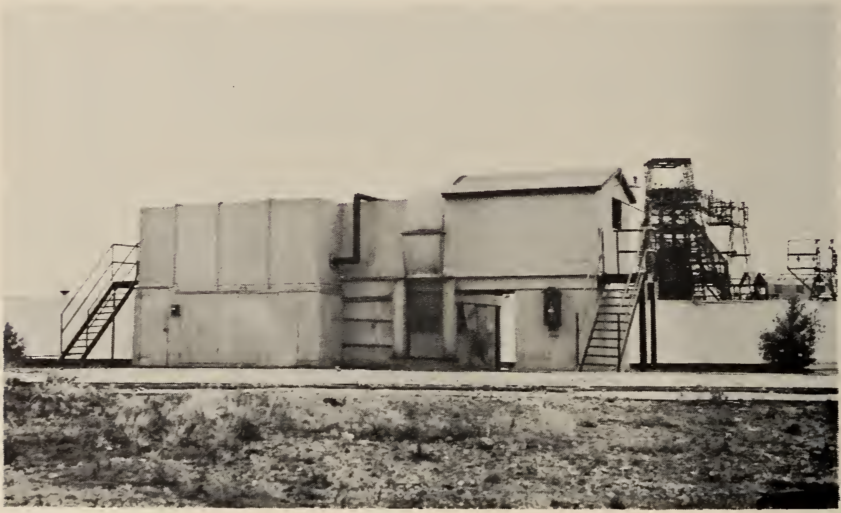

Figure 52.—Ventilating-Heating Plant in Minnesota.

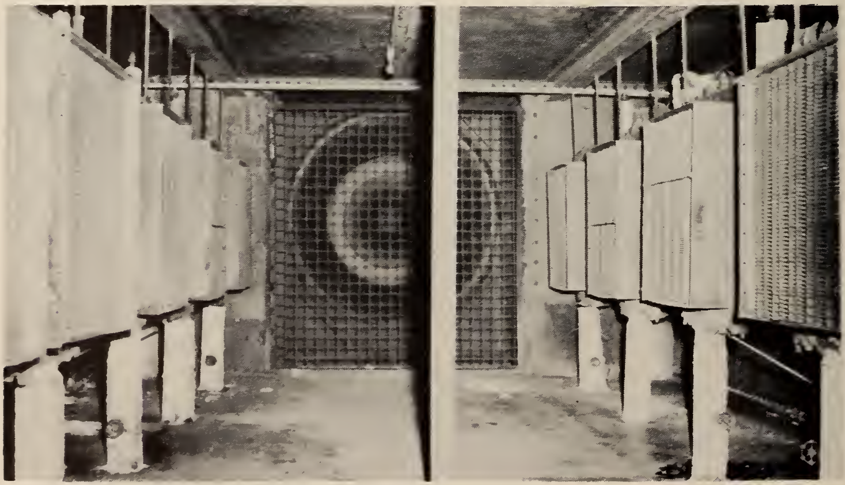

Figure 53.—Coils for Heating Mine Intake Air.

heaters are installed on the intake side of the fan; they are heated by steam and are equipped with individual fans.[83]

All of these plants have been built to similar rigid safety specifications and provide for quick reversal of air current during a fire or other emergency. Floor drains have been provided for the removal of condensation water, and the fresh-air intakes are remote from the possibility of surface fire hazards.

Preheating the air in cold weather has largely replaced the practice of reversing the air current before the air-shaft openings are completely closed with ice. The intermittent thawing and freezing of ice that forms in shafts or adits tend to loosen the wall rock, and in some instances falls of ice have made major shaft repair necessary.

In the Westvaco mine in Wyoming the intake air, which is coursed down a shaft during winter months, is preheated by passing through a grill of pipelines that carry live steam.

Because of high rock temperatures, air-conditioning systems have been installed in some mines to enable men to work in places otherwise too warm for human endurance. Air in mines is cooled by ice or sprays of cool water, by refrigeration, by rapid coursing of cool air brought from the surface or carried slowly through workings with cool walls, and by excluding air coming from hot workings from other sections of a mine.

Air conditioning to improve ventilation has been in use in the Butte mines for a number of years.[84] The temperature of the ground and of mine water at depth has reached 130° F. The mean annual temperature of the surface atmosphere at Butte is about 40° F., with low relative humidity in summer, so that there is almost unlimited cooling power at a favorable temperature range. In the units having the most cooling capacity water is circulated through coils where heat is absorbed from warm mine air, and then the water is cooled by a cooling tower on the surface (figs. 54, 55, and 56). Air is passed through the underground conditioning plants by fans where heat is absorbed by the coils and dust is removed by water sprays and baffle plates. By use of this cooling system, a large part of the air is recirculated, and only enough fresh air must be brought into the mine and discharged as is needed to maintain the oxygen standard of normal mine air. The improvement on a typical level was the reduction in temperature from 88° F. (86° F., wet-bulb) to 76° F. (73° F., wet-bulb). Before operation of the cooling plants the highest rock temperature was 97.5°, and the average temperature for all the working places in the mine was 85.5° F. (82° F., wet-bulb). Later, with three air-conditioning plants in operation and with the highest rock temperature 118° F., the average mine temperature was 82.7° F. (80° F., wet-bulb).

A deep mine in South Africa is air-conditioned by a surface refrigerating plant, through which the air is passed before entering the mine.[85] Approximately 360,000 c. f. m. of air is cooled from 65° to 33°

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[83] Cash, F. E., and Petersen, M. S., Safe Equipment, Guards, and Practices, Lake Superior District Iron-Ore Mines: Bureau of Mines Inf. Circ. 7454, 1948, p. 57.

[84] Richardson, A. S., Progress in Air Conditioning for Ventilation of the Butte Mines: Trans. AIME, vol. 153, 1943, pp. 203–222.

[85] Carrier, W. H., Air Cooling in the Gold Mines on the Rand: Trans. AIME, vol. 141, 1940, pp. 276–287.

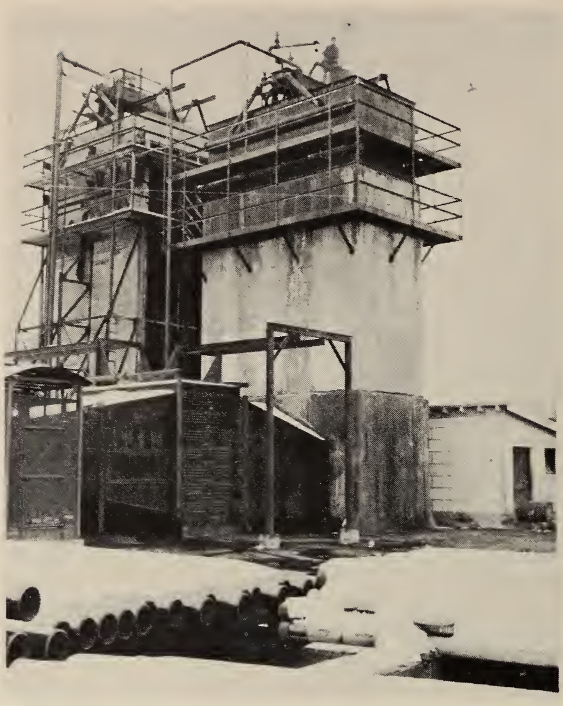

FIGURE 54.—Surface Water-Cooling Tower for Air Conditioning.

and used to cool the mine by absorbing heat as it is circulated downward. Cooling effect in the bottom of the mine averages about 10° wet-bulb (from 85° to 75° F.).

At the Magma mine [86] cooling units have been installed on the lower mine levels to overcome the effects of rock temperatures, which have reached 140°. A refrigerant is employed to cool the water from the coils used to absorb heat from the air. An average cooling of 10° of the mine air has been accomplished. The temperature of 1 winze was reduced from 103° to 81° F. On a lower level the average temperature of working places was reduced from 99° to 89° F.

DUST

Mining officials are giving increased attention to the elimination of harmful concentrations of dust in mine air. The sources of dust in mines and its effects on the health of those exposed to it are discussed in another section of this circular dealing with hazards to health. Dust can be greatly reduced in the mine air by controlling the sources. Also, the concentrations sometimes can be reduced below the harmful limits by providing adequate ventilation. Air-conditioning systems can be effective in removing dust from the air. At Butte the count of particles in air entering and leaving the cooling plants was reduced 42 to 78 percent. Water sprays and sprinkling hose are used widely to allay dust in working places, haulage roads, and ore pockets.

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[86] Foraker, C. B., Underground Cooling at Magma Mine: Min. Cong. Jour., vol. 26, September 1940, pp. 49–50.

Dust-control methods at the Climax mine[87] include the sweeping of areas where dust is formed with clean air from ventilation laterals, through which air currents are split to allow flexible control of ventilation. Regulating doors in the laterals are used to permit control of air currents without installing doors in the haulage drifts. Other methods of allaying or removing dust include wetting down with hose streams and mist sprays underground, but use of water is limited by the cold winter climate. Underground equipment and installations where dust is formed or released are provided with sprays and are enclosed. An exhaust ventilation system is also used on surface units.

At the Greater Butte project, known as the Kelley mine, water-impact-type dust collectors are supplemented by electrostatic dust collectors, which reportedly collect all of the airborne dust created around ore-dumping operations. The water-impact dust collector, with a capacity of 5,000 c. f. m. of air, comprises a 3- by 3½- by 5-foot

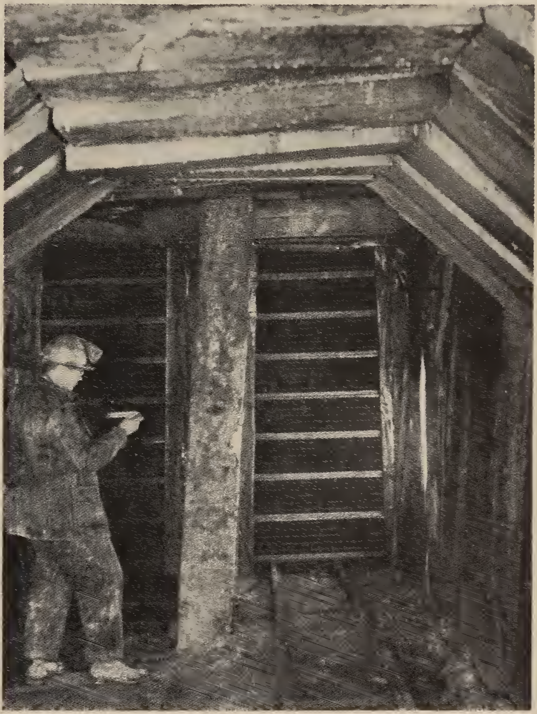

FIGURE 55.—Radiators with Cold-Water Circulation Through Which Hot Mine Air Is Forced.

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[87] Feiss, J. W., Ventilation and Dust Control at Climax Molybdenum: Min. Cong. Jour., vol. 26, July 1940, pp. 12–19.

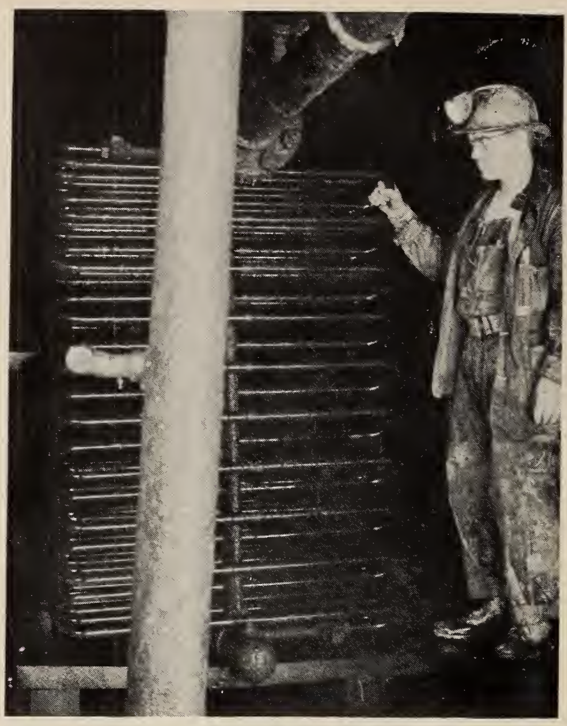

Figure 56.—Cold-Water Sprays on Intake Airway.

glass box containing slotted glass baffle plates and spray nozzles, which deliver the water spray against the plates. Air is drawn through the sprays and perforated plates, which remove the airborne dust particles by the impinger principle. The spray nozzles are mounted on 6-inch centers. The water-impact dust collector is 85 to 90 percent efficient.

It was found that very fine wood fibers from the block-caving operations soon "shorted" the plates of the electrostatic dust collector. By using the water-impact dust collector ahead of the electrostatic dust collector, the combination has proved practicable and efficient in removing dust from mining operations during the extraction of large tonnages of ore.

The water-impact dust collector was developed and patented by the ventilation department of the Anaconda Copper Mining Co.

The Lake Superior district underground iron-ore mines generally have standardized dust-control practices. The midget impinger is used periodically to take dust samples of mine intake and return air and of air in the active working places and haulageways underground. Where dust counts exceeding 5 million particles per cubic foot of air in rock work and 5 to 15 million particles per cubic foot of air in ore are encountered, the dust-control measures are intensified.

The following procedures have been adopted as dust-control measures:

1. The air current at all headings or breasts shall be positive and not less than 2,000 c. f. m.
2. Only the wet-type drill shall be used for drilling.
3. Only clean water shall be used in drilling.
4. All holes shall be started and drilled wet.
5. All working places shall be wet down before and after blasting.
6. Blast holes shall be stemmed tightly before blasting.
7. An approved water blast shall be in operation during blasting.
8. Rock piles shall be soaked with water before and while loading.
9. Where necessary, water mist shall be installed to allay dust.
10. Water sprays shall be installed at conveyor-belt loading and transfer points.
11. Dry haulageways shall be wetted down periodically as needed to allay dust.
12. Wherever possible, contaminated air shall be coursed through inactive sections of the mine.

VOLUME OF AIR

In planning a ventilation system the question of the volume of air that must be supplied frequently arises. There are no fixed rules for determining this volume, since ventilation will have to overcome varying degrees of heat, humidity, depleted air, powder smoke, and harmful dusts. Any estimate of total requirements should ordinarily be based on the amount reaching the working place and not that passing through the mine. The mine should be furnished with enough air to supply all working places that are active at any one time and, in addition, replace leakage losses. Besides supplying the volume of air needed to dilute contaminants, the air currents should have enough velocity to carry these contaminants away. Ordinarily, high velocity should not be used, because it may raise dust into suspension or cause undue discomfort to workers in cool mine workings. The quantity of air needed to satisfy the requirements may be as little as 50 c. f. m. per man under exceptionally favorable conditions or may exceed 1,000 c. f. m. per man. In some development headings it might be necessary to provide 5,000 c. f. m. or even more, regardless of the number of men working in the place.

One large mining company's ventilation engineer has stated:

> Headings in our mines seldom exceed 100 square feet in area, and our experience has been that volumes of 2,000 c. f. m. for an ore heading and 3,000 c. f. m. for rock drifts provide very good ventilation for dust control and smoke removal. A volume of 1,000 c. f. m. has been found satisfactory for ventilating double-compartment raises averaging 5 by 5 feet per compartment. We have maintained volumes ranging from 7,000 c. f. m. to 20,000 c. f. m. for a shaft-sinking operation in which the area was about 300 square feet for a depth of 3,750 feet.

EXAMPLES OF VENTILATING SYSTEMS

A large Canadian mine found that expanded production and future operations made it necessary to have planned, adequate ventilation.[88] In selecting a ventilating system for a mine having 2 shafts 2,400 feet apart and workings at a depth of 2,000 feet, some important mines where ventilation experience had been gained were studied. Working examples of various systems of ventilation were observed, and it was concluded that with an exhaust system the control was simplified and the cost of development and installation was lower than with a forcing system. The volume of air required was determined by observing natural currents during the winter when they were at a peak. In typical stopes a supply of less than 2,000 c. f. m. proved inadequate for prompt removal of dust from working places. Altogether, it was found that 50,000 c. f. m. was adequate for the number of working places in operation plus an allowance for leakage. An airway was planned midway between the two operating shafts. All vitiated air was to be exhausted through the airway, and fresh air would enter through the operating shafts. Heating units were installed to warm the intake air to 40° F. in winter. A propeller-type fan was installed, because its performance curve would allow wide variation of operation without too great loss of efficiency. The structural parts and fixtures surrounding the propellers were streamlined to reduce friction losses, and a reversing switch on the motor permitted quick reversal of the air at any time. The fan will exhaust 50,000 c. f. m. at 0.75 inch water gage and 9 motor hp., or it will exhaust 100,000 c. f. m. at 3.0 inches water gage and 70 motor hp. At both operations the efficiency is 82 percent. The greater output was arranged to care for probable inincreased size of the mines.

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[88] MacDonnell, D. E., Installing Ventilation at Falconbridge: Canadian Min. Jour., vol. 64, March 1943, pp. 131–141.

At a mine in the Northwest[89] plans for future development included extension and improvement of the ventilation system. Improvements in connections and enlargement of airways doubled the volume of the air current and reduced the temperature of the lower levels by 8° F. The outcast exhaust airway was augmented by a system of two-compartment timbered ventilation raises. These raises can be enlarged to four compartments if future needs make it advisable, and the crosscuts by which they are connected to the active workings can be enlarged or additional crosscuts driven.

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[89] Edgar, John, and Knoerr, A. W., Streamlined Ventilation at Sunshine: Min. Cong. Jour., vol. 26, August 1940, pp. 23–26.

EXPLOSION HAZARDS IN METAL AND NONMETALLIC MINES

METHANE IGNITIONS

Numerous ignitions of methane have occurred in certain types of metal mines and tunnels, and some of these ignitions have been mentioned in the discussion of the occurrence of methane in metal mines.

The best and surest precaution against accidents from ignition of explosive mixtures of methane and air is to prevent the accumulation of such concentrations by ventilation that will remove the gas. When it is found that methane may be encountered in tunnels or mine workings, regular checks should be made with a flame safety lamp or preferably with one of the more sensitive detectors, and any gas so found should be removed before any other work is done in that locality. To prevent ignitions of methane in workings where dangerous quantities of the gas may be encountered, "No Smoking" rules should be strictly observed, all open flames should be excluded, only permissible types of electrical equipment should be used, and blasting practices should be controlled very carefully.

A methane explosion in a metal-mine development shaft in Alpena County, Mich., killed five men and injured the sixth in 1952. The ignition occurred during unwatering operations, and the force of the explosion was confined to the shaft and the area immediately surrounding the collar of the shaft. The explosion was probably initiated by a hand-held electric drill operated by 1 of 2 men taking rock samples 180 feet below the collar of the shaft.

In the metal and nonmetallic mines of California there is a record of 20 explosions during the period 1926–53. These explosions resulted in 5 fatal and 34 nonfatal injuries. The cause of the ignitions are as follows: Open lights (carbide) 13, shorted electric light wires 1, smoking 5, and cause unknown 1.

EXPLOSION OF SULFIDE DUST

Sulfide dust has exploded in certain mines.[90] Such explosions usually are attributed to the ignition of fine sulfide dust in suspension by the flame from a blast; they have damaged timber and in some instances caused the death of men who inhaled or were enveloped in the *burning sulfide dust.* A serious explosion occurred in 1943, resulting in the death of 8 men and injury to 17 others from the fumes following an explosion of sulfide dust. The sulfide-dust cloud was created, raised into suspension, and ignited by blasting a number of shots in a stope in heavy sulfide ore. The concussion from the explosion threw a belt from the fan pulley on the surface, the air current reversed, and the fumes were swept back over men going off shift through a haulageway normally on fresh air. The following precautions were adopted to prevent future disasters of this type:

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[90] Gardner, E. D., and Stein, E., Explosibility of Sulfide Dusts in Metal Mines: Bureau of Mines Rept. of Investigations 2863, 1928, 11 pp.

Remove all men from the vicinity when blasting in stopes.
Place an attendant at the fan at these times.
Blast from a control switch at a safe location.
Wet down stopes before blasting.
Limit the number of holes to be blasted in one place.

Dangerous quantities of sulfur dioxide and hydrogen sulfide plus some carbon monoxide have been found after blasting in heavy sulfides. To prevent sulfide-dust explosions, settled dust should not be allowed to accumulate, and all working places should be thoroughly wetted by sprinkling before blasting.

EXPLOSION OF GILSONITE DUST

A widespread gilsonite-dust explosion, which occurred in the No. 1 Incline mine (opencut) November 5, 1953,[91] killed 8 mine employees, the only men in the mine at the time of the explosion, and slightly injured 3 men working on the surface; 5 of the 8 bodies were recovered 15 days after the explosion, and the other 3 bodies were not recovered until March 12–14, 1954.

Owing to the large, open, unsupported wall area and the quantity of debris that fell into the inclined shaft area, recovery of the last 3 bodies was delayed because a shaft had to be sunk 131 feet and a drift driven 126 feet to reach the inclined shaft where the 3 men were working at the time of the explosion and where the bodies were found.

The explosion probably originated on the surface near the bucket elevator when a cloud of gilsonite dust, produced by dumping a car of ore, was ignited probably by electric arcing at the bucket-elevator enclosure or from static discharge. The explosion was propagated throughout the length and depth of the mine.

The No. 1 Incline mine was opened by an inclined shaft, which was extended about 660 feet on a dip of 60° in the top part and 57° in the bottom part. The mine was equipped with a steel headframe, a single-drum hoist geared to an electric motor, and a steel car of 2-ton capacity. The inclined shaft was used for transporting ore, supplies, and men.

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[91] Confer, E. B., Husted, A. C., and Reeder, R. D., Major Explosion Disasters: Bureau of Mines unpublished rept., 1954, 37 pp.

SUGGESTED SAFE PRACTICES FOR FIRES, GASES, AND VENTILATION[92]

SURFACE FIRE PROTECTION

1. Fire protection commensurate with the value of the buildings and their contents should be provided.
2. Fire-fighting equipment should be readily accessible, and the place housing such equipment should be marked plainly.
3. Water lines, valves, and pipe connections on water lines and water tanks should be protected from freezing.
4. Fire lines should be tested frequently, especially in winter, to insure that they are in proper working condition. A record should be kept of the date of each test and the conditions found by the inspector.
5. Fire hydrants should be placed at a safe distance from buildings so that a fire could not render them useless.
6. Fire hydrants should be standard and should fit the hose equipment of the local fire department. Adapters should be provided where necessary.
7. Wrenches or keys for opening waterline valves should be securely attached to the fire hydrant or placed where they are quickly accessible.
8. Waterlines in buildings should be provided with standard fire-hose connections at convenient places; the fire hose should be racked at each outlet, with the hose connected to the waterline, ready for use, and the nozzle should be attached to the hose.
9. Only fireproof buildings should be permitted to adjoin mine shafts, tunnels, or adits.
10. All buildings within a radius of 100 feet from any mine opening should be of fireproof or fire-resistant construction.
11. Fire doors should be erected at mine openings or other effective points so that smoke or fire from outside sources cannot endanger men working underground.
12. Buildings not on tight fire-resistant foundations should be banked with dirt to reduce the fire hazard from lighted cigarettes or other causes.
13. Blacksmih shops should not be placed in the area enclosed by snowsheds or other shelters covering the approach to tunnels or adits. Provision should be made for adequate ventilation of the shop.
14. The area immediately surrounding a substation should be kept free of grass, weeds, and underbrush, which might be set on fire accidentally or intentionally.
15. Transformers placed inside a building should be adequately guarded with fireproof or fire-resistant materials that will prevent fire from spreading if the transformer oil is ignited.
16. If surface transformers containing flammable oil are installed where they present a fire hazard (near mine openings and in or near combustible buildings), means should be provided to drain or confine the oil should the transformer casing rupture.
17. Domed-bottom pails should be hung close to water barrels provided for fire protection.
18. Soda-acid fire extinguishers for use on fires in ordinary combustibles, such as paper, wood, and rubbish, should be provided in buildings; they should be protected against freezing temperatures.
19. Foam fire extinguishers should be provided where flammable liquids are stored or handled; they should be protected against freezing temperatures.
20. Carbon tetrachloride, carbon dioxide, or dry-chemical fire extinguishers should be provided for electrical fires and should be placed where they are easily accessible.
21. Carbon tetrachloride extinguishers should not be used in a confined place.
22. Soda-acid or foam-type extinguishers should not be used on an electrical fire.
23. Water should not be used to extinguish an electrical fire unless a fog nozzle is provided.
24. Dry-chemical or carbon dioxide fire extinguishers should be carried on electric locomotives at all times.
25. Fire-fighting equipment, other than waterlines, should be inspected and tested at least every 6 months, and written records should be kept of each inspection.
26. Fire-fighting equipment should not be used for any purpose but that for which it is intended.
27. A distinctive fire alarm should be provided.
28. Fire-fighting organizations should be maintained on each shift, and fire drills should be held frequently.
29. Heating equipment should be installed in such a manner that fire cannot be caused even if it overheats. Suitable spark arrestors should be installed where needed.

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[92] Bureau of Mines (Some Safety Practices for Metal Mines, Nonmetal Mines Other Than Coal), Mills, Metallurgical Plants, and Quarries: Inf. Cir. 7387, 1946, 56 pp.

30. Blacksmith fires should be quenched with water before attendants leave the shop unattended for protracted periods.
31. Blacksmith shops and surrounding area should be carefully inspected for smoldering fires at the close of the shift.
32. Oxyacetylene, oxyhydrogen, or electric welding should not be started until after adequate protection from fire has been provided. A suitable fire extinguisher should be a part of portable welding units.
33. A careful fire inspection should be made after using oxyacetylene, oxyhydrogen, or electric-welding equipment, particularly if the equipment is used in or immediately above a shaft.
34. "Good housekeeping" is essential to good fire protection and should be enforced at all times.
35. Flammable materials should not be permitted to accumulate in or around any building.
36. Smoking should be prohibited in all buildings in which flammable liquids are stored or dispensed.
37. Grease and lubricating compounds used on machinery should not be allowed to accumulate on the floor or compartment housing the machinery.
38. Tightly covered metal receptacles should be provided for oily waste and rags.
39. Gasoline should not be used for cleaning.
40. Gasoline, oil, or kerosine should not be used for starting fires.
41. Gasoline cans kept on power equipment should be painted red and marked "Gasoline." The cans should be kept tightly capped at all times when not in use and should be inspected frequently for leaks.
42. Carbide cans should be washed out immediately after emptying. While empty carbide cans are being washed, smoking or wearing open lights should be prohibited.
43. A screened container should be provided to screen the unused carbide from miners' lamps. The screened carbide should fall into running water if practicable; the container should not be placed near combustible material or liquids.

UNDERGROUND FIRE PROTECTION

1. Water for fire protection should be available throughout the mine.
2. Waterlines underground should be provided with outlet connections near combustible material.
3. Connections should be provided for turning water into the air line during a fire.
4. A timbered entrance less than 45° from the horizontal should be fireproofed at least 200 feet from the portal.
5. Wood-lined shafts should be fireproofed; if it is not practicable to fireproof them, adequate protection against fire should be provided.
6. Shaft stations should be adequately protected from fire hazards; some mines have a firehouse connection from the pump column that can be used during a fire.
7. If transformers containing flammable oil are installed underground, means should be provided to drain or confine the oil should the transformer casing rupture.
8. Sand or rock dust should be available at electrical installations; in well-ventilated sections dry-chemical or carbon dioxide fire extinguishers should be provided.
9. A stench method of fire warning should be provided where compressed air is used.
10. A well-planned procedure should be adopted and followed by underground employees when the stench warning is given.
11. Practice fire drills should be given once or twice a year and should include a requirement that all underground employees meet at designated places.
12. The stench used as a warning agent should be blown out of the working places as quickly as possible after each practice drill.
13. Fires for heating should not be permitted underground. Open-flame torches, lighted acetylene lamps, and candles should not be left unattended.
14. Before oxyacetylene equipment is used all adjacent dry timber should be thoroughly wet down.
15. If oxyacetylene cutting or welding equipment has been used on any work in the shaft or immediately above it, all adjacent timber should be inspected thoroughly for fire.
16. All timbered shaft stations on levels where oxyacetylene cutting or welding has been done during the shift should be inspected for fire at the close of the shift, and a record of the inspection should be kept.
17. Flammable material should not be allowed to accumulate at or near underground stations.

18. Oils, greases, and other flammable liquids should not be stored at a shaft station.
19. Lubricating oil and grease for use in working places should be in portable, closed, metal containers.
20. Hay, straw, or flammable feed material taken underground should be in compressed bales or covered by tarpaulin or in a container or in a closed car. It should be delivered promptly to the underground stable and stored in a locked fireproof compartment. The amount of hay stored underground at any time should not exceed the amount normally consumed in 48 hours, unless this amount is less than 1 bale.
21. Spontaneous ignitions of waste material in mines containing sulfide ores, carbonaceous shales, or similar strata or having high rock temperatures should be prevented or controlled by sealing, proper mining method, ventilation, or removal of the offending material.

VENTILATION

1. All mines should be ventilated to insure fresh air in all active sections of underground workings, and inactive sections should be fenced or sealed.
2. The main intake and main return air currents in mines should be separate shafts, slopes, or drifts.
3. Airways should be kept clear to permit free passage of air; this requirement applies to nonhaulage aircourses as well as those utilized for haulage or as manways.
4. Haulage and hoisting openings and main and intermediate haulageways preferably should be on intake air.
5. Ventilating currents should be controlled by mechanical means; this is especially important where underground fire hazards are prevalent.
6. Mechanical ventilation should be provided, where necessary to maintain the following conditions:
    a. At least 20 percent oxygen.
    b. Not more than 0.5 percent carbon dioxide.
    c. No harmful amount of dust or poisonous gases.
    d. A velocity of 100 f. p. m. where the relative humidity is 85 percent or more and the dry-bulb temperature is 75° to 85°.
    e. A velocity of 400 f. p. m. where the relative humidity is 85 percent or more and the dry-bulb temperature is above 85°.
7. An air velocity of at least 30 f. p. m. should be maintained in working places after blasting; or if this is not feasible, sufficient air movement should be provided to dilute or to remove blasting fumes with as little delay as possible.
8. Main fans preferably should be located above ground; however, this cannot always be done in metal mines.
9. Main fans should be—
    a. So placed that the return air from the mine cannot be drawn into the intake openings.
    b. Installed to permit prompt reversal of direction of airflow.
    c. In a noncombustible housing. If existing installations do not meet this recommendation, such installations should be made fire-resistant.
    d. Provided with noncombustible air ducts. If existing ducts do not meet this recommendation, they should be made fire-resistant.
    e. Offset from the direct line of the mine workings; the offset distance should be at least 25 feet.
    f. Provided with pressure-recording gage or water gage.
    g. Inspected daily.
    h. Kept free of combustible material for at least 100 feet in all directions.
10. Underground booster fans should be installed so as to prevent recirculation of air.
11. The volume of intake air passing an auxiliary blower-fan installation underground should be at least 1½ times the volume of the air circulated by the blower fan.
12. Where doors are used to course the air, they should be:
    a. Self-closing.
    b. Hung so that they swing to the clearance side.
    c. Installed so as to remain closed should the ventilating current be reversed in an emergency.
13. Changes in ventilation that may affect the safety of the men should be made when the mine is idle and no men are in the mine except those engaged in changing the ventilation.
14. In every sealed area one or more stoppings should be fitted with a pipe or valve to allow sampling the air behind the seals and also to provide a means by which existing hydrostatic pressure can be determined.

CONCLUSIONS

For normal efficient operation the ventilating currents should be positively controlled (mechanically) and should sweep all working places and travelways. The air circulated in the mine should contain not less than 19.5 percent oxygen nor more than 0.5 percent carbon dioxide and no harmful quantities of noxious or poisonous gases.

Fires, gases, and ventilation in all of their phases have a direct bearing on the health, safety, and efficiency of employees in metal and nonmetallic mines. Protection against the occurrence of mine fires and an occasional explosion involves the elimination or control of both the combustible materials and the sources of ignition. The first line of defense is adequate, mechanically controlled ventilation. Good housekeeping will do much to control flammable materials. The prohibition of smoking, use of electric cap lamps, safeguarded blasting, and the proper installation and maintenance of electrical equipment will remove many of the ignition sources.

Other preventive and protective measures are: (1) Fire-fighting facilities; (2) positive warning systems; (3) evacuation methods; (4) formulated procedure plans for emergencies; and (5) employees trained to use emergency equipment and to comply with formulated plans.

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NOTE.—Circulars marked with a dagger (†) are out of print but may be consulted in many libraries. Others may be obtained from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., at the price indicated. Stamps are not accepted in payment for such purchases.

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